THE ROMANCE OF
MODERN INVENTION

CONTAINING INTERESTING DESCRIPTIONS IN
NON-TECHNICAL LANGUAGE OF WIRELESS
TELEGRAPHY, LIQUID AIR, MODERN ARTILLERY, SUBMARINES, DIRIGIBLE TORPEDOES,
SOLAR MOTORS, AIRSHIPS, &c. &c.

BY

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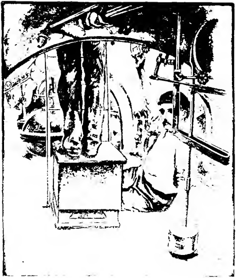

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Preface

THE object of this book is to set before young people in a bright and interesting way, and without the use of technical language, accounts of some of the latest phases of modern invention; and also to introduce them to recent discoveries of which the full development is yet to be witnessed.

The author gratefully acknowledges the help given him as regards both literary matter and illustrations by:—Mr. Cuthbert Hall (the Marconi Wireless Telegraphy Co.); Mr. William Sugg; Mr. Hans Knudsen; Mr. F. C. B. Cole; Mr. E. J. Ryves; Mr. Anton Pollak; the Telautograph Co.; the Parsons Steam Turbine Co.; the Monotype Co.; the Biograph Co.; the Locomobile Co.; the Speedwell Motor Co.

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The Romance of Modern Invention

WIRELESS TELEGRAPHY

ONE day in 1845 a man named Tawell, dressed as a Quaker, stepped into a train at Slough Station on the Great Western Railway, and travelled to London. When he arrived in London the innocent-looking Quaker was arrested, much to his amazement and dismay, on the charge of having committed a foul murder in the neighbourhood of Slough. The news of the murder and a description of the murderer had been telegraphed from that place to Paddington, where a detective met the train and shadowed the miscreant until a convenient opportunity for arresting him occurred. Tawell was tried, condemned, and hung, and the public for the first time generally realised the power for good dormant in the as yet little developed electric telegraph.

Thirteen years later two vessels met in mid-Atlantic laden with cables which they joined and paid out in opposite directions, till Ireland and Newfoundland were reached. The first electric message passed on

August 7th of that year from the New World to the Old. The telegraph had now become a world-power.

The third epoch-making event in its history is of recent date. On December 12, 1901, Guglielmo Marconi, a young Italian, famous all over the world when but twenty-two years old, suddenly sprang into yet greater fame. At Hospital Point, Newfoundland, he heard by means of a kite, a long wire, a delicate tube full of tiny particles of metal, and a telephone ear-piece, signals transmitted from far-off Cornwall by his colleagues. No wires connected Poldhu, the Cornish station, and Hospital Point. The three short dot signals, which in the Morse code signify the letter S, had been borne from place to place by the limitless, mysterious ether, that strange substance of which we now hear so much, of which wise men declare we know so little.

Marconi's great achievement, which was of immense importance, naturally astonished the world. Of course, there were not wanting those who discredited the report. Others, on the contrary, were seized with panic and showed their readiness to believe that the Atlantic had been spanned aërially, by selling off their shares in cable companies. To use the language of the money-market, there was a temporary "slump" in cable shares. The world again woke up—this time to the fact that experiments of which it had heard faintly had at last culminated in a great triumph, marvellous in itself, and yet probably nothing in comparison with the revolution in the transmission of news that it heralded.

The subject of Wireless Telegraphy is so wide that to treat it fully in the compass of a single chapter is impossible. At the same time it would be equally impossible to pass it over in a book written with the object of presenting to the reader the latest developments of scientific research. Indeed, the attention that it has justly attracted entitle it, not merely to a place, but to a leading place; and for this reason these first pages will be devoted to a short account of the history and theory of Wireless Telegraphy, with some mention of the different systems by which signals have been sent through space.

On casting about for a point at which to begin, the writer is tempted to attack the great topic of the ether, to which experimenters in many branches of science are now devoting more and more attention, hoping to find in it an explanation of and connection between many phenomena which at present are of uncertain origin.

What is Ether? In the first place, its very existence is merely assumed, like that of the atom and the molecule. Nobody can say that he has actually seen or had any experience of it. The assumption that there is such a thing is justified only in so far as that assumption explains and reconciles phenomena of which we have experience, and enables us to form theories which can be scientifically demonstrated correct. What scientists now say is this: that everything which we see and touch, the air, the infinity of space itself, is permeated by a *something*, so subtle that, no matter how continuous a thing may seem, it is but a concourse of atoms separated by this something, the Ether. Reasoning drove them to this conclusion.

It is obvious that an effect cannot come out of nothing. Put a clock under a bell-glass and you hear the ticking. Pump out the air and the ticking becomes inaudible. What is now not in the glass that was there before? The air. Reason, therefore, obliges us to conclude that air is the means whereby the ticking is audible to us. No air, no sound. Next, put a lighted candle on the further side of the exhausted bell-glass. We can see it clearly enough. The absence of air does not affect light. But can we believe that there is an absolute gap between us and the light? No! It is far easier to believe that the bell-glass is as full as the outside atmosphere of the something that communicates the sensation of light from the candle to the eye.

In like manner we believe that the ether brings us light from the far-off sun and from the stars—more remote still.

It also brings us heat from the sun. How can we account for the fact that both heat and light are carried right across the vast "empty" spaces lying between us and the sun, except by the assumption that the so-called empty space is filled with the ether.

The heat from a distant fire reaches us by the same means. Hold a screen between yourself and a fire and then quickly remove it. Instantly the heat strikes you; it *flashes* upon you as it were. It is no current of hot air which *conveys* it to you, nor is there any medium, so far as we can see, which *conducts* it to you. Moreover, this swiftly moving heat travels in straight lines, so that we can shield ourselves from it, just as we can shield ourselves from light. In fact, it behaves itself almost exactly as light does, and we are forced to the conclusion that it is caused, like light, by radiation through the ether.

Heat so carried is therefore spoken of as "radiant heat." We shall also find that there is what we might call "radiant" electricity—electrical energy, that is, which is not conducted along wires, but which is flashed through the ether just as light and radiant heat are.

It is to Professor Clerk Maxwell that we mainly owe this particular branch of knowledge, for he it was who about fifty years ago first formed the idea that there were electric waves in the ether similar to the light and heat waves, but differing from them, as they differ from one another, in their length. Just as the famous astronomer Adams discovered a planet (Neptune) by calculations, before anyone had seen it, so this marvellous mathematician, Clerk Maxwell, discovered upon paper, before we had any means of perceiving them, the electric waves which now carry our "wireless" messages.

This theory of Professor Maxwell set scientific people to work to find a means of making these electric waves, and of detecting their presence when made. Among them was a young German professor named Hertz, and he, in the eighties of last century, discovered how to make and how to detect these electric waves.

So light is always, and heat and electricity are sometimes, carried by waves in the ether. These waves all travel at the same speed, namely, 186,000 miles per second, and in a great many ways they all behave alike. Their difference, as has been said already, is in their length, which means the distance from the crest of one wave to the crest of the next.

Those of a length of about 34,000 to the inch give us the sensation of red light. About 64,000 to the inch cause the sensation of violet light. Waves but a few thousandths of an inch constitute "radiant" heat, while those from about a quarter of an inch up to a number of miles form "radiant" electricity. It is these last which carry the wireless telegrams.

Experiments show that the waves must be of the up-and-down variety, and not of the to-and-fro kind which carry sound through the air. They are well illustrated by means of a tablecloth upon a table.

Take one corner of the cloth and shake it up and down, when ripples will chase each other across it. The cloth will not move across as the ripples do, be it noted, but they will be formed by the particles of cloth moving up and down in succession. The ether, therefore, does not move in the direction in which the waves go, but the individual particles of which the ether is made up have an up-and-down motion in succession. The waves travel towards us or from us, therefore, while the ether itself remains practically stationary. This makes it much more easy to realise the wonderfully subtle things which the waves are able to do.

It is well to think of the waves as being the *cause* of light, heat, and electrical forces, and not as being those things themselves. Waves cause light; waves (or radiant heat) cause heat; waves (or radiant electricity) cause electric currents. This distinction between cause and effect will greatly help us to avoid confused thinking.

The waves have different powers of penetration. For example, light waves pass easily through clear glass, while heat waves are partially stopped thereby. Heat waves are absorbed by a dull black surface and turned almost entirely into ordinary heat, while they are reflected or driven back by a bright surface.

And just as a black surface absorbs the heat waves and turns them into sensible or "feelable" heat, so an electrical conductor, such as a metal wire, absorbs the electrical waves and turns them into the ordinary electrical force, while non-conductors, like a sheet of glass or a brick wall, allow them to pass.

The earliest known form of wireless telegraphy is transmission of messages by light. A man on a hill lights a lamp or a fire. This represents his instrument for agitating the ether into waves, which proceed straight ahead with incredible velocity until they reach the receiver, the eye of a man watching at a point from which the light is visible.

Then came electric telegraphy.

At first a complete circuit (two wires) was used. But in 1838 it was discovered that if instead of two wires only one was used, the other being replaced by an earth connection, not only was the effect equally powerful, but even double of what it was with the metallic circuit.

Thus the first step had been taken towards wireless electrical telegraphy.

The second was, of course, to abolish the other wire.

This was first effected by Professor Morse, who, in 1842, sent signals across the Susquehanna River without metallic connections of any sort. Along each bank of the river was stretched a wire three times as long as the river was broad. In the one wire a battery and transmitter were inserted, in the other a receiving instrument or galvanometer. Each wire terminated at each end in a large copper plate sunk in the water. Morse's conclusions were that provided the wires were long enough and the plates large enough messages could be transmitted for an indefinite distance; the current passing from plate to plate, though a large portion of it would be lost in the water.[1]

About the same date a Scotchman, James Bowman Lindsay of Dundee, a man as rich in intellectual attainments as he was pecuniarily poor, sent signals in a similar manner across the River Tay. In September, 1859, Lindsay read a paper before the British Association at Dundee, in which he maintained that his experiments and calculations assured him that by running wires along the coasts of America and Great Britain, by using a battery having an acting surface of 130 square feet and immersed sheets of 3000 square feet, and a coil weighing 300 lbs., he could send messages from Britain to America. Want of money prevented the poor scholar of Dundee from carrying out his experiments on a large enough scale to obtain public support. He died in 1862, leaving behind him the reputation of a man who in the face of the greatest difficulties made extraordinary electrical discoveries at the cost of unceasing labour; and this in spite of the fact that he had undertaken and partly executed a gigantic dictionary in fifty different languages!

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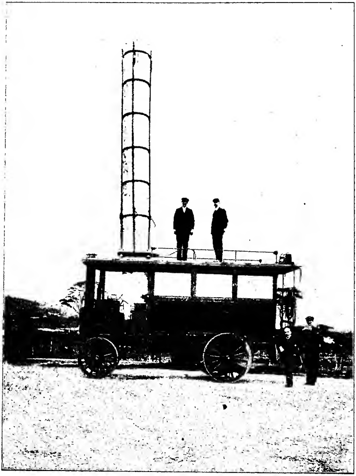
[1] It is here proper to observe that the term *wireless* telegraphy, as applied to electrical systems, is misleading, since it implies the absence of wires; whereas in all systems wires are used. But it is generally understood that by wireless telegraphy is meant telegraphy without *metal connections*.

The transmission of electrical signals through matter, metal, earth, or water, is effected by *conduction*, or the *leading* of the currents in a circuit. When we come to deal with aërial transmission, *i.e.* where one or both wires are replaced by the ether, then two methods are possible, those of *induction* and Hertzian waves.

To take the induction method first. Whenever a current is sent through a wire magnetism is set up in the ether surrounding the wire, which becomes the core of a "magnetic field." The magnetic waves extend for an indefinite distance on all sides, and on meeting a wire *parallel* to the electrified wire *induce* in it a *dynamical* current similar to that which caused them. Wherever electricity is present there is magnetism also, and *vice versâ*. Electricity produces magnetism—magnetism produces electricity. The invention of the Bell telephone enabled telegraphers to take advantage of this law.

In 1885 Sir William Preece, later consulting electrical engineer to the General Post-Office, erected near Newcastle two insulated squares of wire, each side 440 yards long. The squares were horizontal, parallel, and a quarter of a mile apart. On currents being sent through the one, currents were detected in the other by means of a telephone, which remained active even when the squares were separated by 1000 yards. Sir William Preece thus demonstrated that signals could be sent without even an earth connection, *i.e.* entirely through the ether. In 1886 he sent signals between



M. Marconi's Travelling Station for Wireless Telegraphy.

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two parallel telegraph wires 4½ miles apart. And in 1892 established a regular communication between Flatholm, an island fort in the Bristol Channel, and Lavernock, a point on the Welsh coast 3⅓ miles distant.

The inductive method might have attained to greater successes had not a formidable rival appeared in the Hertzian waves.

In 1887 Professor Hertz discovered that if the discharge from a Leyden jar were passed through wires containing an air-gap across which the discharge had to pass, sparks would also pass across a gap in an almost complete circle or square of wire held at some distance from the jar. This "electric eye," or detector, could have its gap so regulated by means of a screw that at a certain width its effect would be most pronounced, under which condition the detector, or receiver, was "in tune" with the exciter, or transmitter. Hertz thus established three great facts, that—

(*a*) A discharge of static (*i.e.* collected) electricity across an air-gap produced strong electric waves in the ether on all sides.

(*b*) That these waves could be *caught.*

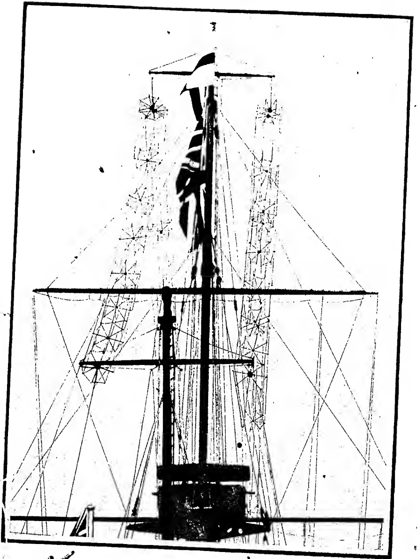
(*c*) That under certain conditions the catcher worked most effectively.

Out of these three discoveries has grown the now familiar wireless telegraphic system of Marconi. He, in common with Professor Branly of Paris, Sir Oliver Lodge, Dr. J. A. Fleming, and many others, have done great work during the last decade or so, in perfecting the methods and apparatus used.

Marconi's transmitter consists of three parts—a battery; an induction coil, terminating in a pair of brass balls, one on each side of the air-gap; and a Morse transmitting-key. Upon the key being depressed, a current from the battery passes through the coil and accumulates electricity on the brass balls until its tension causes it to leap from one to the other many millions of times, in what is called a spark. The longer the air-gap the greater must be the accumulation before the leap takes place, and the greater the power of the vibrations set up. Marconi found that by connecting a kite or balloon covered with tinfoil by an aluminium wire with one of the balls, the effect of the waves was greatly increased. Sometimes he replaced the kite or balloon by a conductor placed on poles two or three hundred feet high, or by the mast of a ship.

We now turn to the receiver.

In 1879 Professor D. E. Hughes observed that a microphone, in connection with a telephone, produced sounds in the latter even when the microphone was at a distance of several feet from coils through which a current was passing. A microphone, it may be explained, is in its simplest form a loose connection in an electric circuit, which causes the current to flow in fits and starts at very frequent intervals. He discovered that a metal microphone stuck, or cohered, after a wave had influenced it, but that a



"Wireless" on a Battleship. On warships, wireless telegraphy is universal. Here we see the "antennæ" on a British Dreadnought. The "spider's-webs are light frames which keep the parallel wires from touching. Antennæ so made are called "Admiralty type."

carbon microphone was self-restoring, *i.e.* regained its former position of loose contact as soon as a wave effect had ceased.

In 1891 Professor Branly of Paris produced a "coherer," which was nothing more than a microphone under another name. Five years later Marconi somewhat altered Branly's contrivance, and took out a patent for a coherer of his own.

It is a tiny glass tube, about two inches long and a tenth of an inch in diameter inside. A wire enters it at each end, the wires terminating in two silver plugs fitting the bore of the tube. A space of $\frac{1}{32}$ inch is left between the plugs, and this space is filled with special filings, a mixture of 96 parts of nickel to 4 of silver, and the merest trace of mercury. The tube is exhausted of almost all its air before being sealed.

This little gap filled with filings is, except when struck by an electric wave, to all practical purposes a non-conductor of electricity. The metal particles touch each other so lightly that they offer great resistance to a current.

But when a Hertzian wave flying through the ether strikes the apparatus, the particles suddenly press hard on one another, and make a bridge through which a current can pass. The current works a "relay," or circuit through which a stronger current passes, opening and closing it as often as the coherer is influenced by a wave. The relay actuates a tapper that gently taps the tube after each wave-influence, causing the particles to *de*cohere in readiness for the succeeding wave, and also a Morse instrument for recording words in dots and dashes on a long paper tape.

The coherer may be said to resemble an engine-driver, and the "relay" an engine. The driver is not sufficiently strong to himself move a train, but he has strength enough to turn on steam and make the engine do the work. The coherer is not suitable for use with currents of the intensity required to move a Morse recorder, but it easily switches a powerful current into another circuit.

What really happens is this. The oscillating currents at the sending station send forth the waves. These striking the receiving apparatus generate currents in it like those which gave them birth, only much feebler. It is the function of the coherer to detect these extremely feeble currents.

The particular sizes of waves used are of such lengths as 300, 500, 1000, or 2000 feet, the two latter especially. Now the waves, as we know, travel at the rate of 186,000 miles per second, and so in order to generate waves, say, 1000 feet long, the electricity has to send off waves at the rate of just about a million per second. At that speed, therefore, the current must oscillate to and fro in the apparatus.

The modern receiver is an improvement upon the original glass tube coherer, but the principle of it is much the same, and the signals are received by the operator by sound in a telephone receiver fixed on his head.

Want of space forbids a detailed account of Marconi's successes with his improved instruments, but the appended list will serve to show how he gradually increased the distance over which he sent signals through space.

In 1896 he came to England. That year he signalled from a room in the General Post-Office to a station on the roof 100 yards distant. Shortly afterwards he covered 2 miles on Salisbury Plain.

In May, 1897, he sent signals from Lavernock Point to Flatholm, 3½ miles. This success occurred at a critical time, for Sir W. Preece had already, as we have seen, bridged the same gap by his induction method, and for three days Marconi failed to accomplish the feat with his apparatus, so that it appeared as though the newer system were the less effective of the two. But by carrying the transmitting instrument on to the beach below the cliff on which it had been standing, and joining it by a wire to the pole already erected on the top of the cliff, Mr. Marconi, thanks to a happy inspiration, did just what was needed; he got a greater length of wire to send off his waves from. Communication was at once established with Flatholm, and on the next day with Bream Down, on the other side of the Bristol Channel, and 8⅜ miles distant. Then we have—

Needles Hotel to Swanage . .	17½	miles.
Salisbury to Bath	34	„
French Coast to Harwich . . .	90	„
Isle of Wight to The Lizard . .	196	„
At Sea (1901)	350	„
Dec. 12, 1901, England to America	2099	„

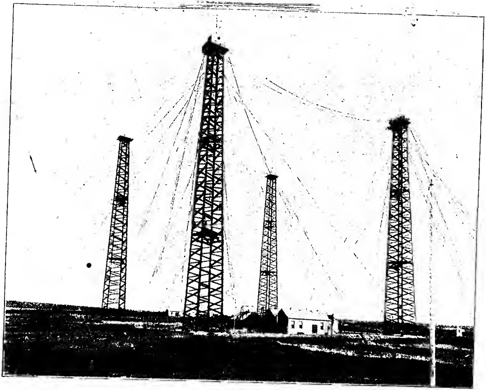
A more pronounced, though perhaps less sensational, success than even this last occurred at the end of February, 1902. Mr. Marconi, during a voyage to America on the s.s. *Philadelphia* remained in communication with Poldhu, Cornwall, until the vessel was 1550 miles distant, receiving messages on a Morse recorder for any one acquainted with the code to read. Signals arrived for a further 500 miles, but owing to his instruments not being of sufficient strength, Mr. Marconi could not reply.

When the transatlantic achievement was announced at the end of 1901, there was a tendency in some quarters to decry the whole system. The critics laid their fingers on two weak points.

In the first place, they said, the speed at which the messages could be transmitted was too slow to insure that the system would pay. Mr. Marconi replied that there had been a time when one word per minute was considered a good working rate across the Atlantic cable; whereas he had already sent twenty-two words per minute over very long distances. A further increase of speed was only a matter of time.

The second objection raised centred on the lack of secrecy resulting from signals being let loose into space to strike any instrument within their range; and also on the confusion that must arise when the ether was traversed by many sets of electric waves.

The young Italian inventor had been throughout



Poldhu Towers, the Station put down by the Marconi Wireless Telegraph Company, Limited, for carrying on a system of transatlantic wireless telegraphy between England and America. From the four towers are suspended the aerial wires which are carried into the buildings in the centre. The towers are 215 feet in height, and are made of wood.

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his experiments aware of these defects and sought means to remedy them.

A simple experiment will suffice to show the principle on which this remedy proceeds. Tune one string of a violin to exactly the same pitch as a certain string on a piano. Then while holding the violin in your hand get a friend to play on the piano. All the strings and the body of the violin will vibrate as the other instrument is played, but whenever that particular note is struck to which the violin string has been tuned it will respond with peculiar readiness. Then if the pianist plays more and more softly there will come a time when the violin will respond only to that corresponding note on the piano.

In like manner it has been found possible to "tune" one wireless apparatus to agree with another. It will then pick up easily all the signals sent out by those stations with which it is in tune, but will not be appreciably affected by any others.

The tuning is done by various electrical adjustments which we need not go into here. It is sufficient to explain that an operator can so arrange his apparatus that it sends out ether waves of a certain length or distance apart, and when so adjusted it will also respond very readily to waves of that same length. All the ships and shore stations have their particular "notes" or wave-lengths, which are known to all the operators. When not at work, but ready to be called up if need be, each apparatus is kept adjusted for its own special note. The operator who wishes to open up communication tunes his apparatus to the note of the station whom he wishes to call, and so the conversation is opened.

The "deeper" the note the more suitable is it for long distances, for the longer waves seem to penetrate more easily the intervening space. Thus certain stations and ships are equipped for longer distances than others. Most ships have short-distance apparatus designed for a few hundred miles, but that does not prevent them from communicating with the shore all through a voyage across the Atlantic, for example, for their messages can be "relayed." This means sent to another ship, which in turn will hand it on until it reaches its destination.

All the installations on the Atlantic liners, as well as the stations on both shores, are under the control of the Marconi Company, and the operators are fully aware of the approximate positions of the various ships. A shore station has a message for ship A, but she is beyond reach. Ship B, however, is known to be within call, and so the message is thrown, as it were, to ship B, which, it may be, has to pass it on to ship C, which is in communication with ship A, and so after being relayed twice it is received on ship A and duly handed to the person for whom it is intended.

Thus travellers are kept in touch with their friends, or their business, even while many miles from land. Nay more, they are kept up to date in all the news of the world, for on some large ships little news-sheets are published containing the latest events of interest as heard by the Marconi man in his little cabin on the deck.

It is a curious life which "sparks," as his shipmates call him, has to lead. Sitting there with his telephone instrument fixed on his head he hears in the dots and dashes of the Morse code, which to him are as clear as the plainest language, all sorts of curious conversations going on, and messages both private and public.

Sometimes he hears signals of distress. Who can picture the feelings of the Marconi operator on the *Carpathia* on that fateful Sunday when, just taking a final look into his cabin before turning in for the night, he heard the *Titanic* calling. "We are sinking" came the message. Just at first he would hardly realise what that meant—the mighty *Titanic*, the greatest vessel ever launched, the unsinkable—sinking!! We can imagine how he would fly to the captain with the fateful news, and then rush back to his post to try and send the doomed ship a message of cheer, telling how the *Carpathia* had turned and was already racing to the rescue; how he would endeavour to keep in touch so as to know what was going on, and his feelings of despair when the signals ceased and he could get no more news, the silence seeming to tell of the final tragedy taking place just beyond their reach.

But it is not always that the call comes too late. Had it not been for singular ill-fortune the calls of the *Titanic* would have reached nearer ships and help would have arrived in time. In other cases ships have been saved by the timely succour brought by the wireless messages, or when the ships have been lost the lives of those on board have been saved.

Regarded as a life-saving invention alone—apart from its other spheres of usefulness—the wireless telegraph is one of the most beneficent products of this wonderful age.

It should be explained that the instruments described in this chapter are the simplest forms, and that there are others in general use, some of which will be referred to in the later chapter on Wireless Telephony. The underlying principle is the same in all.

HIGH-SPEED TELEGRAPHY.

THE wonderful developments of wireless telegraphy must not make us forget that some very interesting and startling improvements have been made in connection with the ordinary wire-circuit method: notably in the matter of speed.

At certain seasons of the year or under special circumstances which can scarcely be foreseen, a great rush takes place to transmit messages over the wires connecting important towns. Now, the best telegraphists can with difficulty keep up a transmitting speed of even fifty words a minute for so long as half-an-hour. The Morse alphabet contains on the average three signals for each letter, and the average length of a word is six letters. Fifty words would therefore contain between them 900 signals, or fifteen a second. The strain of sending or noting so many for even a brief period is very wearisome to the operator.

Means have been found of replacing the telegraph clerk, so far as the actual signalling is concerned, by mechanical devices.

In 1842 Alexander Bain, a watchmaker of Thurso, produced what is known as a "chemical telegraph." The words to be transmitted were set up in large metal type, all capitals, connected with the positive pole of a battery, the negative pole of which was connected to earth. A metal brush, divided into five points, each terminating a wire, was passed over the metal type. As often as a division of the brush touched metal it completed the electric circuit in the wire to which it was joined, and sent a current to the receiving station, where a similar brush was passing at similar speed over a strip of paper soaked in iodide of potassium. The action of the electricity decomposed the solution, turning it blue or violet. The result was a series of letters divided longitudinally into five belts separated by white spaces representing the intervals between the contact points of the brush.

The Bain Chemical Telegraph was able to transmit the enormous number of 1500 words per minute; that is, at ten times the rate of ordinary conversation! But even when improvements had reduced the line wires from five to one, the system, on account of the method of composing the message to be sent, was not found sufficiently practical to come into general use.

A more modern way of increasing the speed at which messages can be passed over a line is to send several at once. There are four methods of doing this—Duplex, Diplex, Quadruplex, and Multiplex.

In "Diplex" working two messages pass at one and the same time in the *same* direction. It is easy to make a receiving instrument which will respond to a strong current, but not to a weak one. It is equally easy to make one that will answer to a positive current, either weak or strong, but not to a negative one, or *vice versâ*. In other words, one type of instrument is affected by changes of *strength* in the current, while the other is operated by a change in *direction*, but *not* by a variation in strength. So there are two clerks at each end, and a current is always flowing in the wire. One of the sending clerks depresses his key and the current is suddenly increased in strength. One of the receiving clerks thereupon sees the signal come in on his receiving instrument. Meanwhile the second sending clerk depresses his key and the direction of the current is changed; whereupon the second receiving clerk sees that signal come in on the second instrument. Thus each pair of clerks, one sending and one receiving, can work quite independently of the other.

In the Duplex method of working the messages pass in opposite directions. It must not be thought, however, that the currents pass each other upon the wire, for that would be impossible. By calling the two stations A and B, we can explain it thus.

The sender at A sends off a current. If the sender at B is not working, that current goes straight to the B receiver and is duly noted. If, however, both senders try to send current simultaneously no current at all passes, but, the two currents opposing each other, each one is forced to escape along a branch wire through its own receiving instrument. So under these conditions A does not work B's receiver, but he pushes B's own current back and makes it work it instead. In like manner B's current pushes A's back. So each works his own receiver, and the result is exactly the same as if the two currents had passed each other on the line.

Now the change-of-strength signals of the Diplex can thus be Duplexed, and so can the change-of-direction signals, by which method four signals, two each way, can be sent at once, forming the Quadruplex method.

Finally we come to the Multiplex, of which there are several varieties.

In one of these the receiving instruments are a species of telephone. Six men may be sitting listening to six telephones in which they hear six different messages in the dots and dashes of Morse, and all are coming over one wire. Each sending key is connected with a tuning-fork in such a way that when depressed it sends out not a single steady current, but a rapid series of tiny currents, one for every vibration of the fork. Each of the six keys has a fork of a different rate of vibration, and so each sends off its dots and dashes in a series of tiny puffs of current following each other at a rate which depends upon the note of the fork. All six may be working at once, so that the jumble of currents passing through the wire at one time must be so confused as to be absolutely unintelligible—at least so it seems. As a matter of fact, however, each telephone can be so tuned that it responds only to the series of currents coming from one fork, and to no others. Thus each one picks out from the apparently inextricable confusion just those currents intended for it. Each telephone reproduces, in the form of long and short sounds, those currents sent off by the fork with which it is in tune.

Then this system can be duplexed, in the manner already explained, so that six men can be sending and six receiving at each end: twelve messages passing over the wire at once.

Another method of using the same wire is that of distributing among the instruments the time during which they are in contact with the line.

Let us suppose that four transmitters are sending messages simultaneously from London to Edinburgh. Wires from all four instruments are led into a circular contact-maker, divided into some hundreds of insulated segments connected in rotation with the four transmitters. Thus instrument A will be joined to segments 1, 5, 9, 13; instrument B to segments 2, 6, 10, 14; instrument C with segments 3, 7, 11, 15; and so on.

Along the top of the segments an arm, connected with the telegraph line to Edinburgh, revolves at a uniform rate. For about $\frac{1}{500}$ of a second it unites a segment with an instrument. If there are 150 segments on the "distributor," and the arm revolves three times a second, each instrument will be put into contact with the line rather oftener than 110 times per second. And if the top speed of fifty words a minute is being worked to, each of the fifteen signals occurring in each second will be on the average divided among seven moments of contact.

A similar apparatus at Edinburgh receives the messages. It is evident that for the system to work satisfactorily, or even to escape dire confusion, the revolving arms must run at a level speed in perfect unison with one another. When the London arm is over segment 1, the Edinburgh arm must cover the same number. The greatest difficulty in multiplex telegraphy has been to adjust the timing exactly.

Paul la Cour of Copenhagen invented for driving the arms a device called the Phonic Wheel, as its action was regulated by the vibrations of a tuning-fork. The wheel, made of soft iron, and toothed on its circumference, revolves at a short distance from the pole of a magnet. As often as a current enters the magnet the latter attracts the nearest tooth of the wheel; and if a regular series of currents pass through it the motion of the wheel will be uniform. M. la Cour produced the regularity of current impulses in the motor magnet by means of a tuning-fork, which is unable to vibrate more than a certain number of times a second, and at each vibration closed a circuit sending current into the magnet. To get two tuning-forks of the same note is an easy matter; and consequently a uniformity of rotation at both London and Edinburgh stations may be insured.

So sensitive is this "interrupter" system that as many as sixteen messages can be sent simultaneously, which means that a single wire is conveying from 500 to 800 words a minute. We can easily understand the huge saving that results from such a system; the cost of instruments, interrupter, &c., being but small in proportion to that of a number of separate conductors.

The word-sending capacity of a line may be even further increased by the use of automatic transmitters able to work much faster in signal-making than the human brain and hand. Sir Charles Wheatstone's Automatic Transmitter has long been used in the Post-Office establishments.

The messages to be sent are first of all punched on a long tape with three parallel rows of perforations. The central row is merely for guiding the tape through the transmitting machine. The positions of the holes in the two outside rows relatively to each other determine the character of the signal to be sent. Thus, when three holes (including the central one) are abreast, a Morse "dot" is signified; when the left-hand hole is one place behind the right hand, a "dash" will be telegraphed.

In the case of a long communication the matter is divided among a number of clerks operating punching machines. Half-a-dozen operators could between them punch holes representing 250 to 300 words a minute; and the transmitter is capable of despatching as many in the same time, while it has the additional advantage of being tireless.

The action of the transmitter is based upon the reversal of the direction or nature of current. The punched tape is passed between an oscillating lever, carrying two points, and plates connected with the two poles of the battery. As soon as a hole comes under a pin the pin drops through and makes a contact.

At the receiving end the wire is connected with a coil wound round the pole of a permanent bar-magnet. Such a magnet has what is known as a north pole and a south pole, the one attractive and the other repulsive of steel or soft iron. Any bar of soft iron can be made temporarily into a magnet by twisting round it a few turns of a wire in circuit with the poles of a battery. But which will be the north and which the south pole depends on the *direction* of the current. If, then, a current passes in one direction round the north pole of a permanent magnet it will increase the magnet's attractive power, but will decrease it if sent in the other direction.

The "dot" holes punched in the tape being abreast cause first a positive and then a negative current following at a very short interval; but the "dash" holes not being opposite allow the positive current to occupy the wires for a longer period. Consequently the Morse marker rests for correspondingly unequal

the reports
of the captains which
ply between europe and
america state that shi
ps have met with dozen
s of icebergs some over
100 feet high

Specimens of the punched tape used for transmitting messages by the Pollak-Virag system, and of a message as it is delivered by the receiving machine.

[*To face p.* 34.

periods on the recording "tape," giving out a series of dots and dashes, as the inker is snatched quickly or more leisurely from the paper.

The Wheatstone recorder has been worked up to 400 words a minute, and when two machines are by the Duplex method acting together this rate is of course doubled.

The Wheatstone apparatus can be worked, if need be, on the Quadruplex method. Its speed may be even further increased by the use of a more novel form of receiver, in which the currents pass straight to a point, trailing upon a strip of chemically prepared paper. When the current is flowing from this point a bluish mark is drawn upon the strip, and so the dots and dashes are recorded. There are thus no mechanical working parts in the receiver, and so a much greater speed can be attained—say, 1000 or 1200 words a minute, without duplexing even.

To obviate the time lost in perforating the strip, and later in transcribing the dots and dashes into ordinary language, Hughes invented his writing telegraph. In this there is only one current for each letter—the Morse code is entirely abandoned. A rapidly revolving arm is driven by a motor of some sort. Its outer end sweeps round over a circle of vertical pins, one for each letter. Normally these lie below the path of the arm, but when a key in a piano-like keyboard is depressed, the pin which corresponds with the key is raised, so that it makes contact with the arm at its next revolution.

At the other end there is a disc revolving in *perfect unison* with the arm, and on its edge in raised characters are the letters, while a little hammer stands upraised, ready to strike any letter as it passes. Just as the pin which represents K, for example, is under the arm, the type K on the wheel will be under the hammer; and the same with any other letter. If the K pin be raised, then the arm as it comes round touches it, and instantly a current departs to the distant station. Arriving there it works the hammer, which drives a piece of paper against the type on the edge of the wheel, and so imprints upon it the letter K. In the same way the raising of any pin causes to be printed the letter to which it corresponds. The secret of success, as you will see, is that arm and disc shall so work together that the moment the arm touches a pin is just the moment when the corresponding type is under the hammer. So exact must this be that allowance has to be made for the time which the current takes to traverse the wire.

This method is said to work 25 per cent. faster than a system using the Morse code, in addition to which there is no strip to punch at the sending end, nor to translate at the receiving end.

A French inventor, Baudot by name, has gone one better, working on somewhat the same lines, but obtaining a faster speed still.

Some other wonderful instruments there is but room to mention.

The Murray is one of these. Here an instrument, apparently like a typewriter, punches holes in paper strip according as the keys are pressed. That slip fed into the transmitter causes the receiving instrument to punch similar strip, which in turn can be fed into a writing machine which transcribes the message into ordinary language.

The Creed system is somewhat similar, except that it uses an ordinary Wheatstone Transmitter instead of a special one.

But perhaps the most wonderful of all telegraph instruments is the Pollak-Virag, which writes with a pencil of light upon photographic paper. "Beautiful apparatus," the Chief Engineer of the British Post Office has called it, and the specimens of its work must fill us all with admiration.

As usual there is the paper strip to commence with, but it is punched with many rows of holes of various sizes. As it is drawn through the instrument little points make electrical contact whenever a hole passes them. Thus many currents of varying degrees of strength and duration are fed to the lines, of which there are two.

Each line leads to a telephone receiver, the diaphragm of which vibrates as the currents come in. Little metal arms convey these delicate movements to a tiny mirror, in such a way that a beam of light reflected by the mirror is thrown upwards or downwards by the motion of one telephone, and sideways by that of the other. Now by combining up-and-down and side-to-side motions, we can make any manner of line or curve that we require. And in that way the varying currents sent along the wires can cause the mirror to draw with the pencil of light the complicated curves of ordinary handwriting. The pencil is sharpened by being passed through a lens, and so the beautiful regular writing is produced.

The strip of photographic paper passes automatically through developing and fixing baths, emerging from the machine ready to be read. Six hundred to a thousand words a minute can be sent in this marvellous way.

THE TELEPHONE.

A COMMON enough sight in any large town is a great sheaf of fine wires running across the streets and over the houses. If you traced their career in one direction you would find that they suddenly terminate, or rather combine into cables, and disappear into the recesses of a house, which is the Telephone Exchange. If you tracked them the other way your experience would be varied enough. Some wires would lead you into public institutions, some into offices, some into snug rooms in private houses. At one time your journey would end in the town, at another you would find yourself roaming far into the country, through green fields and leafy lanes until at last you ran the wire to earth in some large mansion standing in a lordly park. Perhaps you might have to travel hundreds of miles, having struck a "trunk" line connecting two important cities; or you might even be called upon to turn fish and plunge beneath the sea for a while, groping your way along a submarine cable.

In addition to the visible overhead wires that traverse a town there are many led underground through special conduits. And many telephone wires never come out of doors at all, their object being to furnish communication between the rooms of the same house. The telephone and its friend, the electric-bell, are now a regular part of the equipment of any large premises. The master of the house goes to his telephone when he wishes to address the cook or the steward, or the head-gardener or the coachman. It saves time and labour.

Should he desire to speak to his town-offices he will, unless connected direct, "ring up" the Exchange, into which, as we have seen, flow all the wires of the subscribers to the telephone system of that district. The ringing-up is usually done by rapidly turning a handle which works an electric magnet and rings a bell in the Exchange. The operator there, generally a girl, demands the number of the person with whom the ringer wants to speak, rings up that number, and connects the wires of the two parties.

In some exchanges, *e.g.* the new Post-Office telephone exchanges, the place of electric-bells is taken by lamps, to the great advantage of the operators, whose ears are thus freed from perpetual jangling. The action of unhooking the telephone receiver at the subscriber's end sends a current into a relay which closes the circuit of an electric lamp opposite the subscriber's number in the exchange. Similarly, when the conversation is completed the action of hanging up the receiver again lights another lamp of a different colour, giving the exchange warning that the wires are free again.

In some places, notably in America, the operator is sometimes entirely dispensed with. A subscriber is able, by means of a mechanical contrivance, to put himself in communication with any other subscriber unless that subscriber is engaged, in which case a dial records the fact.

The popularity of the telephone may be judged from the fact that, according to Sir John Gavey, the telephone wires in use in the world would reach nearly half-way to the sun. In America and Germany the telephone is even more universally employed than in England. In the thinly populated prairies of West America the farm-houses are often connected with a central station many miles off, from which they receive news of the outer world and are able to keep in touch with one another. We are not, perhaps, as a nation sufficiently alive to the advantages of an efficient telephone system; and on this account many districts remain telephoneless because sufficient subscribers cannot be found to guarantee use of a system if established. It has been seriously urged that much of our country depopulation might be counteracted by a universal telephone service, which would enable people to live at a distance from the towns and yet be in close contact with them. At present, for the sake of convenience and ease of "getting at" clients and customers, many business men prefer to have their homes just outside the towns where their business is. A cheap and efficient service open to every one would do away with a great deal of travelling that is necessary under existing circumstances, and by making it less important to live near a town allow people to return to the country.

Even Norway has a good telephone system. The telegraph is little used in the more thinly inhabited districts, but the telephone may be found in most unexpected places, in little villages hidden in the recesses of the fiords. Switzerland, another mountainous country, but very go-ahead in all electrical matters, is noted for the cheapness of its telephone services. At Berne or Geneva a subscriber pays £4 the first year, £2, 12s. the second year, and but £1, 12s. the third. Contrast these charges with those of New York, where £15, 10s. to £49, 10s. is levied annually according to service.

The telephone as a public benefactor is seen at its best at Buda-Pesth, the twin-capital of Hungary. In 1893, one Herr Theodore Buschgasch founded in that city a "newspaper"—if so it may be called—worked entirely on the telephone. The publishing office was a telephone exchange; the wires and instruments took the place of printed matter. The subscribers were to be informed entirely by ear of the news of the day.

The *Telefon Hirmondo* or "Telephonic Newsteller," as the "paper" was named, has more than six thousand subscribers, who enjoy their telephones for the very small payment of eighteen florins, or about a penny a day, for twelve hours a day.

News is collected at the central office in the usual journalistic way by telephone, telegraph, and reporters.

It is printed by lithography on strips of paper six inches wide and two feet long. These strips are handed to "stentors," or men with powerful and trained voices, who read the contents to transmitting instruments in the offices, whence it flies in all directions to the ears of the subscribers.

These last know exactly when to listen and what description of information they will hear, for each has over his receiver a programme which is rigidly adhered to. It must be explained at once that the *Telefon Hirmondo* is more than a mere newspaper, for it adds to its practical use as a first-class journal that of entertainer, lecturer, preacher, actor, political speaker, musician. The *Telefon* offices are connected by wire with the theatres, churches, and public halls, drawing from them by means of special receivers the sounds that are going on there, and transmitting them again over the wires to the thousands of subscribers. The Buda-Pesthian has therefore only to consult his programme to see when he will be in touch with his favourite actor or preacher. The ladies know just when to expect the latest hints about the fashions of the day. Nor are the children forgotten, for a special period is set aside weekly for their entertainment in the shape of lectures or concerts.

The advertising fiend, too, must have his say, though he pays dearly for it. On payment of a florin the stentors will shout the virtues of his wares for a space of twelve seconds. The advertising periods are sandwiched in between items of news, so that the subscriber is bound to hear the advertisements unless he is willing to risk missing some of the news if he hangs up his receiver until the "puff" is finished.

Thanks to the *Telefon Hirmondo* the preacher, actor, or singer is obliged to calculate his popularity less by the condition of the seats in front of him than by the number of telephones in use while he is performing his part. On the other hand, the subscriber is spared a vast amount of walking, waiting, cab-hire, and expense generally. In fact, if the principle is much further developed, we shall begin to doubt whether a Buda-Pesthian will be able to discover reasons for getting out of bed at all if the receiver hanging within reach of his hand is the entrance to so many places of delight. Will he become a very lazy person; and what will be the effect on his entertainers when they find themselves facing benches that are used less every day? Will the sight of a row of telephone trumpets rouse the future Liddon, Patti, Irving, or Gladstone to excel themselves? It seems rather doubtful. Telephones cannot look interested or applaud.

What is inside the simple-looking receiver that hangs on the wall beside a small mahogany case, or rests horizontally on a couple of crooks over the case? In the older type of instrument the transmitter and receiver are separate, the former fixed in front of the case, the latter, of course, movable so that it can be applied to the ear. But improved patterns have transmitter and receiver in a single movable handle, so shaped that the earpiece is by the ear while the mouthpiece curves round opposite the mouth. By pressing a small lever with the fingers the one or the other is brought into action when required.

The construction of the instrument, of which we are at first a little afraid, and with which we later on learn to become rather angry, is in its general lines simple enough. The first practical telephone, constructed in 1876 by Graham Bell, a Scotchman, consisted of a long wooden or ebonite handle down the centre of which ran a permanent bar-magnet, having at one end a small coil of fine insulated wire wound about it. The ends of the wire coil are led through the handles to two terminals for connection with the line wires At a very short distance from the wire-wound pole of the magnet is firmly fixed by its edges a thin circular iron plate, covered by a funnel-shaped mouthpiece.

The iron plate is, when at rest, concave, its centre being attracted towards the pole of the magnet. When any one speaks into the mouthpiece the sound waves agitate the diaphragm (or plate), causing its centre to move inwards and outwards. The movements of the diaphragm affect the magnetism of the magnet, sometimes strengthening it, sometimes weakening it, and consequently exciting electric currents of varying strength in the wire coil. These currents passing through the line wires to a similar telephone excite the coil in it, and in turn affect the magnetism of the distant magnet, which attracts or releases the diaphragm near its pole, causing undulations of the air exactly resembling those set up by the speaker's words. To render the telephone powerful enough to make conversation possible over long distances it was found advisable to substitute for the one telephone a special transmitter, and to insert in the circuit a battery giving a much stronger current than could possibly be excited by the magnet in the telephone at the speaker's end.

Edison in 1877 invented a special transmitter made of carbon. He discovered that the harder two faces of carbon are pressed together the more readily will they allow current to pass; the reason probably being that the points of contact increase in number and afford more bridges for the current.

Accordingly his transmitter contains a small disc of lampblack (a form of carbon) connected to the diaphragm, and another carbon or platinum disc against which the first is driven with varying force by the vibrations of the voice.

The Edison transmitter is therefore in idea only a modification of the microphone. It acts as a *regulator* of current, in distinction to the Bell telephone, which is only an *exciter* of current. Modern forms of telephones unite the Edison transmitter with the Bell receiver.

The latter is extremely sensitive to electric currents, detecting them even when of the minutest power. We have seen that Marconi used a telephone in his famous transatlantic experiments to distinguish the signals sent from Cornwall. A telephone may be used with an "earth return" instead of a second wire; but as this exposes it to stray currents by induction from other wires carried on the same poles or from the earth itself, it is now usual to use two wires, completing the metallic circuit. Even so a subscriber is liable to overhear conversations on wires neighbouring his own; the writer has lively recollections of first receiving news of the relief of Ladysmith in this manner.

Owing to the "capacity" of wires in submarine cables and the consequent difficulty of forcing currents through them, the telephone is at present not used in connection with submarine lines of more than a very moderate length. England has, however, been connected with France by a telephone cable from St. Margaret's Bay to Sangatte, 23 miles; and Scotland with Ireland, Stranraer to Donaghadee, 26 miles. The former cable enables speech between London and Marseilles, a distance of 900 miles; and the latter makes it possible to speak from London to Dublin *viâ* Glasgow. The longest direct line in existence is that between New York and Chicago, the complete circuit of which uses 1900 miles of stout copper wire, raised above the ground on poles 35 feet high.

The efficiency of the telephone on a well laid system is so great that it makes very little difference whether the persons talking with one another are 50 or 500 miles apart. There is no reason why a

Cape-to-Cairo telephone should not put the two extremities of Africa in clear vocal communication. We may even live to see the day when a London business man will be able to talk with his agent in Sydney, Melbourne, or Wellington.

A step towards this last achievement has been taken by M. Germain, a French electrician, who has patented a telephone which can be used with stronger currents than are possible in ordinary telephones.

The telephone that we generally use has a transmitter which permits but a small portion of the battery power to pass into the wires, owing to the resistance of the carbon diaphragm. The weakness of the current is to a great extent compensated by the exceedingly delicate nature of the receiver.

M. Germain has reversed the conditions with a transmitter that allows a very high percentage of the current to flow into the wires, and a comparatively insensitive receiver. The result is a "loud-speaking telephone"—not a novelty, for Edison invented one as long ago as 1877—which is capable of reproducing speech in a wonderfully powerful fashion.

M. Germain, with the help of special tubular receivers, has actually sent messages through a line having the same resistance as that of the London-Paris line, so audibly that the words could be heard fifteen yards from the receiver in the open air!

WIRELESS TELEPHONY.

Reference has already been made under the head of Wireless Telegraphy to the efforts of Sir William Preece to connect two distant stations without wires but by the aid of induction, the currents in one wire inducing similar currents in a distant wire. By passing the exciting current through a telephone transmitter it can be made to vary in accordance with the waves of sound, and of course the induced currents will vary in like manner, so that by passing them through a telephone receiver they become converted back into the same sound.

Another form of wireless telephony which has been tried with a certain success is based upon two facts. One is that if an electric arc light be fed mainly with continuous or steadily flowing current, but with a smaller varying current added to it, the brilliance of the light will vary as the varying current does. Thus the sound waves can be converted by a telephone instrument into variations in the brilliance of the light.

The second is that a certain metal called Selenium, while it will normally conduct electricity a little, has its conducting power much increased if light fall upon it.

So an arc lamp arranged as just described is made by suitable reflectors to throw its light to a distance, after the manner of a searchlight, the rays falling upon some selenium at the distant station. Thus the currents from the telephone transmitter vary the light of the arc, this in turn varies the resistance of the selenium, and that again varies the strength of a current flowing through it, and through a telephone receiver. By this roundabout way the sounds poured into the transmitter are reproduced in the receiver.

These two methods, the induction method and the use of light and selenium, might have been developed further but for the successful working of the wireless telegraphy of Marconi, which soon turned the thoughts of inventors to the possibility of transmitting by similar methods the minute varying currents necessary to convey sound as well as the longer ones needed for simple dots and dashes.

To commence with, it was necessary to have a means by which a steady stream of ether waves could be set coursing through space, instead of the splashes, as we might call them, caused by the induction-coil apparatus already described. R. A. Fessenden, one of the cleverest workers in this branch of electricity, constructed a special dynamo for this purpose, which could send current rushing up and down an antenna at the unthinkable speed of 75,000 times per second. This was just the sort of thing wanted, for the regular alternation caused by a dynamo means a regular continuous series of waves flowing away from the antenna through the ether. There are mechanical difficulties, however, in the way of using a machine running at such a high speed as is necessary to generate these rapid currents, a difficulty which does not apply to the Poulson Arc, invented by the famous Danish experimenter of that name.

This interesting form of apparatus consists of an electric arc formed between a rod of copper and a rod of carbon, the whole being enclosed in a gas-tight box full of the vapour of methylated spirit. Current from an ordinary dynamo at 200 volts or thereabouts is led to the copper rod and back from the carbon rod. At the same time two other wires are connected, one to the copper and one to the carbon, forming a second circuit, in which are inserted a condenser and a coil.

By a curious means, which there is not room to explain here, as soon as the main (steady) current flows from the dynamo through the arc, a series of currents commence to surge or oscillate to and fro in the other circuit. This oscillation, of a million or so per second, is much more rapid than that from the high-speed dynamo and just as regular—exactly what is needed for wireless telephony. A telephone transmitter can be introduced into the second circuit in which these rapid currents are oscillating, and then their force will vary in accordance with the waves of sound spoken into the mouthpiece. The currents, too, which these oscillations produce in the neighbouring antenna will vary also with the sound, and so will the ether waves which they cause. Thus we see how a steady, and very rapid, series of waves can be sent forth, continually varying in strength in accordance with the rise and fall of the sound waves.

We can now turn to the receiving apparatus by which these waves are detected and turned back into waves of sound. The coherer would not do. It does not respond readily enough, nor is it delicate enough in its action. There are, however, several other forms of detector which will do, of which one must serve as a specimen. We will take Fessenden's Electrolytic Detector.

This consists of a cup of dilute sulphuric acid, or something of that nature, in which are immersed a plate of silver and a tiny thread of platinum wire. A battery is connected to one of these and to a telephone receiver, in such a way that current flows from the battery through the receiver to the plate, through the liquid to the platinum wire, and thence back to the battery. As soon as this current begins to flow it causes hydrogen to be deposited upon the platinum wire in a film which stops the current entirely. But the plate and the platinum wire are also connected to the antenna. The ether waves from the distant station when they strike the antenna produce in it oscillating currents similar to those which gave them birth, and these flow to the detector, and pass through the liquid in much the same way that the current from the battery did to commence with, only with this difference. Whereas the steady current from the battery creates the hydrogen film and so chokes itself, so to speak, the oscillating currents disturb and destroy the film. Thus the oscillating currents from the antenna clear the way for the battery current, which, however, is choked again as soon as they stop. So the battery current, though more powerful than the antenna currents, is controlled by them. When they flow, it flows; when they stop, it stops; when they are strong, it is strong too; when they are weak, so is it. And this battery current passes through the telephone, so that its variations are converted into sound waves audible to anyone who puts the receiver to his ear.

To sum up this chain of causes and effects—the telephone transmitter varies the currents at the sending station, and so varies the ether waves sent out. The ether waves arriving at the receiving end produce currents in the antenna like those which caused them. They in turn regulate the flow of current through the telephone receiver and so form the sounds.

So successful is this form of telephony that it is no exaggeration to say that it is easier to telephone wirelessly, if such a word may be used, than through a submarine cable of equivalent length. The troubles already mentioned which occur when telephoning through submarine cables seem more difficult to overcome than those which face wireless telephony, so that for communicating speech or other sounds across the water there is a great future before the latter.

THE PHONOGRAPH.

EVEN if Thomas Edison had not done wonders with electric lighting, telephones, electric torpedoes, new processes for separating iron from its ore, telegraphy, animated photography, and other things too numerous to mention, he would still have made for himself an enduring name as the inventor of the Phonograph. He has fitly been called the "Wizard of the West" from his genius for conjuring up out of what would appear to the multitude most unpromising materials startling scientific marvels, among which none is more truly wizard-like than the instrument that is as receptive of sound as the human ear, and of illimitable reproducing power. By virtue of its elfishly human characteristic, articulate speech, it occupies, and always will occupy, a very high position as a mechanical wonder. When listening to a telephone we are aware of the fact that the sounds are immediate reproductions of a living person's voice, speaking at the moment and at a definite distance from us; but the phonographic utterances are those of a voice perhaps stilled for ever, and the difference adds romance to the speaking machine.

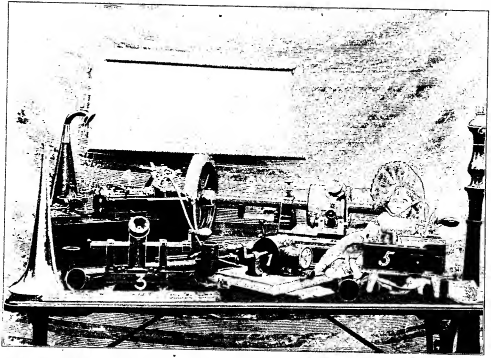
The Phonograph was born in 1876. As we may imagine, its appearance created a stir. A contributor to the *Times* wrote in 1877: "Not many weeks have passed since we were startled by the announcement that we could converse audibly with each other, although hundreds of miles apart, by means of so many miles of wire with a little electric magnet at each end.

"Another wonder is now promised us—an invention purely mechanical in its nature, by means of which words spoken by the human voice can be, so to speak, stored up and reproduced at will over and over again hundreds, it may be thousands, of times. What will be thought of a piece of mechanism by means of which a message of any length can be spoken on to a plate of metal—that plate sent by post to any part of the world and the message absolutely respoken in the very voice of the sender, purely by mechanical agency? What, too, shall be said of a mere machine, by means of which the old familiar voice of one who is no longer with us on earth can be heard speaking to us in the very tones and measure to which our ears were once accustomed?"

The first Edison machine was the climax of research in the realm of sound. As long ago as 1856 a Mr. Leo Scott made an instrument which received the formidable name of Phonautograph, on account of its capacity to register mechanically the vibrations set up in the atmosphere by the human voice or by musical instruments. A large metal cone like the mouth of an ear-trumpet had stretched across its smaller end a membrane, to which was attached a very delicate tracing-point working on the surface of a revolving cylinder covered with blackened paper. Any sound entering the trumpet agitated the membrane, which in turn moved the stylus and produced a line on the cylinder corresponding to the vibration. Scott's apparatus could only record. It was, so to speak, the first half of the phonograph. Edison, twenty years later, added the active half. His machine, as briefly described in the *Times*, was simple; so very simple that many scientists must have wondered how they failed to invent it themselves.

A metal cylinder grooved with a continuous square-section thread of many turns to the inch was mounted horizontally on a long axle cut at one end with a screw-thread of the same "pitch" as that on the cylinder. The axle, working in upright supports, and furnished with a heavy fly-wheel to render the rate of revolution fairly uniform, was turned by a handle. Over the grooved cylinder was stretched a thin sheet of tinfoil, and on this rested lightly a steel tracing-point, mounted at the end of a spring and separated from a vibrating diaphragm by a small pad of rubber tubing. A large mouthpiece to concentrate sound on to the diaphragm completed the apparatus.

To make a record with this machine the cylinder was moved along until the tracing-point touched one extremity of the foil. The person speaking into the mouthpiece turned the handle to bring a fresh surface of foil continuously under the point, which, owing to the thread on the axle and the groove on the



A unique group of Phonographs. 1. The oldest phonograph in existence, now in South Kensington Museum. 2. Tinfoil instrument 3. A cheaper form of the same. 4. A "spectacle-form" graphophone. 5. An exactly similar instrument, half-size scale. 6. A doll fitted with cylinder being of the same pitch, was always over the groove, and burnished the foil down into it to a greater or less depth according to the strength of the impulses received from the diaphragm.

The record being finished, the point was lifted off the foil, the cylinder turned back to its original position, and the point allowed to run again over the depressions it had made in the metal sheet. The latter now became the active part, imparting to the air by means of the diaphragm vibrations similar in duration and quality to those that affected it when the record was being made.

It is interesting to notice that the phonograph principle was originally employed by Edison as a telephone "relay." His attention had been drawn to the telephone recently produced by Graham Bell, and to the evil effects of current leakage in long lines. He saw that the amount of current wasted increased out of proportion to the length of the lines—even more than in the proportion of the squares of their lengths—and he hoped that a great saving of current would be effected if a long line were divided into sections and the sound vibrations were passed from one to the other by mechanical means. He used as the connecting link between two sections a strip of moistened paper, which a needle, attached to a receiver, indented with minute depressions, that handed on the message to another telephone. The phonograph proper, as a recording machine, was an after-thought.

Edison's first apparatus, besides being heavy and clumsy, had in practice faults which made it fall short of the description given in the *Times*. Its tone was harsh. The records, so far from enduring a thousand repetitions, were worn out by a dozen. To these defects must be added a considerable difficulty in adjusting a record made on one machine to the cylinder of another machine.

Edison, being busy with his telephone and electric lamp work, put aside the phonograph for a time. Graham Bell, his brother, Chichester Bell, and Charles Sumner Tainter, developed and improved his crude ideas. They introduced the Graphophone, using easily removable cylinder records. For the tinfoil was substituted a thin coating of a special wax preparation on light paper cylinders. Clockwork-driven motors replaced the hand motion, and the new machines were altogether more handy and effective. As soon as he had time Edison again entered the field. He conceived the solid wax cylinder, and patented a small shaving apparatus by means of which a record could be pared away and a fresh surface be presented for a new record.

The phonograph or graphophone of to-day is a familiar enough sight; but inasmuch as our readers may be less intimately acquainted with its construction and action than with its effects, a few words will now be added about its most striking features.

In the first place, the record remains stationary while the trumpet, diaphragm and stylus pass over it. The reverse was the case with the tinfoil instrument.

The record is cut by means of a tiny sapphire point having a circular concave end very sharp at the edges, to gouge minute depressions into the wax. The point is agitated by a delicate combination of weights and levers connecting it with a diaphragm of French glass $\frac{1}{150}$ inch thick. The reproducing point is a sapphire ball of a diameter equal to that of the gouge. It passes over the depressions, falling into them in turn and communicating its movements to a diaphragm, and so tenderly does it treat the records that a hundred repetitions do not inflict noticeable damage.

It is a curious instance of the manner in which man unconsciously copies nature that the reproducing attachment of a phonograph contains parts corresponding in function exactly to those bones of the ear known as the Hammer, Anvil, and Stirrup.

To understand the inner working of the phonograph the reader must be acquainted with the theory of sound. All sound is the result of impulses transmitted by a moving body usually reaching the ear through the medium of the air. The quantity of the sound, or loudness, depends on the violence of the impulse; the tone, or note, on the number of impulses in a given time (usually fixed as one second); and the quality, or *timbre*, as musicians say, on the existence of minor vibrations within the main ones.

If we were to examine the surface of a phonograph record (or phonogram) under a powerful magnifying glass we should see a series of scoops cut by the gouge in the wax, some longer and deeper than others, long and short, deep and shallow, alternating and recurring in regular groups. The depth, length, and grouping of the cuts decides the nature of the resultant note when the reproducing sapphire point passes over the record—at a rate of about ten inches a second.

The study of a tracing made on properly prepared paper by a point agitated by a diaphragm would enable us to understand easily the cause of that mysterious variation in *timbre* which betrays at once what kind of instrument has emitted a note of known pitch. For instance, let us take middle C, which is the result of a certain number of atmospheric blows per second on the drum of the ear. The same note may come from a piano, a violin, a banjo, a man's larynx, an organ, or a cornet; but we at once detect its source. It is scarcely imaginable that a piano and a cornet should be mistaken for one another. Now, if the tracing instrument had been at work while the notes were made successively it would have recorded a wavy line, each wave of exactly the same *length* as its fellows, but varying in its *outline* according to the character of the note's origin. We should notice that the waves were themselves wavy in section, being jagged like the teeth of a saw, and that the small secondary waves differed in size.

The minor waves are the harmonics of the main note. Some musical instruments are richer in these harmonics than others. The fact that these delicate variations are recorded as minute indentations in the wax and reproduced is a striking proof of the phonograph's mechanical perfection.

Furthermore, the phonograph registers not only these composite notes, but also chords or simultaneous combinations of notes, each of which may proceed from a different instrument. In its action it here resembles a man who by constant practice is able to add up the pounds, shillings, and pence columns in his ledger at the same time, one wave system overlapping and blending with another.

The phonograph is not equally sympathetic with all classes of sounds. Banjo duets make good records, but the guitar gives a poor result. Similarly, the cornet is peculiarly effective, but the bass drum disappointing. The deep chest notes of a man come from the trumpet with startling truth, but the top notes on which the soprano prides herself are often sadly "tinny." The phonograph, therefore, even in its most perfect form is not the equal of the exquisitely sensitive human ear; and this may partially be accounted for by the fact that the diaphragm in both recorder and reproducer has its own fundamental note which is not in harmony with all other notes, whereas the ear, like the eye, adapts itself to any vibration.

Yet the phonograph has an almost limitless répertoire. It can justly be claimed for it that it is many musical instruments rolled into one. It will reproduce clearly and faithfully an orchestra, an instrumental soloist, the words of a singer, a stump orator, or a stage favourite. Consequently we find it everywhere—at entertainments, in the drawing-room, and even tempting us at the railway station or other places of public resort to part with our superfluous pence. In the nursery it delights the possessors of ingeniously constructed dolls which, on a button being pressed, and concealed machinery brought into action, repeat some well-known childish melody.

It must not be supposed that the phonograph is nothing more than a superior kind of scientific toy. More serious duties than those of mere entertainment have been imposed upon it.

At election times it is to be found at the street corners advocating the particular tenets of the party to whom the particular instrument belongs. In one respect it has an advantage over the orator whose words it is repeating, for it calmly ignores all interruptions and robs the poor "heckler" of his sport.

Since the pronunciation of a foreign language is acquired by constant imitation of sounds, the phonograph, instructed by an expert, has been used to repeat words and phrases to a class of students until the difficulties they contain have been thoroughly mastered. The sight of such a class hanging on the lips—or more properly the trumpet—of a phonograph gifted with the true Parisian accent may be common enough in the future.

The Phonograph

As a mechanical secretary and substitute for the shorthand writer the phonograph has certainly passed the experimental stage. Its daily use by some of the largest business establishments in the world testify to its value in commercial life. Many firms, especially American, have invested heavily in establishing phonograph establishments to save labour and final expense. The manager, on arriving at his office in the morning, reads his letters, and as the contents of each is mastered, dictates an answer to a phonograph cylinder which is presently removed to the typewriting room, where an assistant, placing it upon her phonograph and fixing the tubes to her ears, types what is required. It is interesting to learn that at Ottawa, the seat of the Canadian Government, phonographs are used for reporting the parliamentary proceedings and debates.

There is therefore a prospect that, though the talking-machine may lose its novelty as an entertainer, its practical usefulness will be largely increased. And while considering the future of the instrument, the thought suggests itself whether we shall be taking full advantage of Mr. Edison's notable invention if we neglect to make records of all kinds of intelligible sounds which have more than a passing interest. If the records were made in an imperishable substance they might remain effective for centuries, due care being taken of them in special depositories owned by the nation. To understand what their value would be to future generations we have only to imagine ourselves listening to the long-stilled thunder of Earl

Chatham, to the golden eloquence of Burke, or the passionate declamations of Mrs. Siddons. And in the narrower circle of family interests how valuable a part of family heirlooms would be the phonograms containing a vocal message to posterity from Grandfather this, or Great-aunt that, whose portraits in the drawing-room album do little more than call attention to the changes in dress since the time when their subjects faced the camera!

Record-Making and Manufacture. — Phonographic records are of two shapes, the cylindrical and the flat, the latter cut with a volute groove continuously diminishing in diameter from the circumference to the centre. Flat records are used in the Gramophone —a reproducing machine only. Their manufacture is effected by first of all making a record on a sheet of zinc coated with a very thin film of wax, from which the sharp steel point moved by the recording diaphragm removes small portions, baring the zinc underneath. The plate is then flooded with an acid solution, which eats into the bared patches, but does not affect the parts still covered with wax. The etching complete, the wax is removed entirely, and a cast or electrotype *negative* record made from the zinc plate. The indentations of the original are in this represented by excrescences of like size; and when the negative block is pressed hard down on to a properly prepared disc of vulcanite or celluloid, the latter is indented in a manner that reproduces exactly the tones received on the "master" record.

Cylindrical records are made in two ways, by moulding or by copying. The second process is extremely simple. The "master" cylinder is placed on a machine which also rotates a blank cylinder at a short distance from and parallel to the first. Over the "master" record passes a reproducing point, which is connected by delicate levers to a cutting point resting on the "blank," so that every movement of the one produces a corresponding movement of the other.

This method, though accurate in its results, is comparatively slow. The *moulding* process is therefore becoming the more general of the two. Edison has recently introduced a most beautiful process for obtaining negative moulds from wax positives. Owing to its shape, a zinc cylinder could not be treated like a flat disc, as, the negative made, it could not be detached without cutting. Edison, therefore, with characteristic perseverance, sought a way of electrotyping the wax, which, being a non-conductor of electricity, would not receive a deposit of metal. The problem was how to deposit on it.

Any one who has seen a Crookes' tube such as is used for X-ray work may have noticed on the glass a black deposit which arises from the flinging off from the negative pole of minute particles of platinum. Edison took advantage of this repellent action; and by enclosing his wax records in a vacuum between two gold poles was able to coat them with an infinitesimally thin skin of pure gold, on which silver or nickel could be easily deposited. The deposit being sufficiently thick the wax was melted out and the surface of the electrotype carefully cleaned. To make castings it was necessary only to pour in wax, which on cooling would shrink sufficiently to be withdrawn. The delicacy of the process may be deduced from the fact that some of the sibilants, or hissing sounds of the voice, are computed to be represented by depressions less than a millionth of an inch in depth, and yet they are most distinctly reproduced! Cylinder records are made in two sizes, 2½ and 5 inches in diameter respectively. The larger size gives the most satisfactory renderings, as the indentations are on a larger scale and therefore less worn by the reproducing point. One hundred turns to the inch is the standard pitch of the thread; but in some records the number is doubled.

Phonographs, Graphophones, and Gramophones are manufactured both in America and England, where large factories, equipped with most perfect plant and tools, work day and night to cope with the orders that flow in freely from all sides. One factory alone turns out a thousand machines a day, ranging in value from a few shillings to forty pounds each. Records are made in England on a large scale; and now that the Edison-Bell firm has introduced the unbreakable celluloid form their price has decreased. By means of the Edison electrotyping process a customer can change his record without changing his cylinder. He takes the cylinder to the factory, where it is heated, placed in the mould, and subjected to great pressure which drives the soft celluloid into the mould depressions; and behold! in a few moments "Auld Lang Syne" has become "Home, Sweet Home," or whatever air is desired. Thus altering records is very little more difficult than getting a fresh book at the circulating library.

THE PHOTOGRAPHOPHONE.

This instrument is a phonograph working entirely by means of light and electricity.

The flame of an electric lamp is brought under the influence of sound vibrations which cause its brilliancy to vary at every alteration of pitch or quality.

The light of the flame is concentrated through a lens on to a travelling photographic sensitive film, which, on development in the ordinary way, is found to be covered with dark and bright stripes proportionate in tone to the strength of the light at different moments. The film is then passed between a lamp and a selenium plate connected with an electric circuit and a telephone. The resistance of the selenium to the current varies according to the power of the light thrown upon it. When a dark portion of the film intercepts the light of the lamp the selenium plate offers high resistance; when the light finds its way through a clear part of the film the resistance weakens. Thus the telephone is submitted to a series of changes affecting the "receiver." As in the making of the record speech-vibrations affect light, and the light affects a sensitive film; so in its reproduction the film affects a sensitive selenium plate, giving back to a telephone exactly what it received from the sound vibrations.

One great advantage of Mr. Ruhmer's method is that from a single film any number of records can be printed by photography; another, that, as with the Telegraphone (see below), the same film passed before a series of lamps successively is able to operate a corresponding number of telephones.

THE TELEPHONOGRAPH.

Having dealt with the phonograph and the telephone separately, we may briefly consider one or two ingenious combinations of the two instruments. The word Telephonograph signifies an apparatus for recording sounds sent from a distance. It takes the place of the human listener at the telephone receiver.

Let us suppose that a Reading subscriber wishes to converse along the wires with a friend in London, but that on ringing up his number he discovers that the friend is absent from his home or office. He is left with the alternative of either waiting till his friend returns, which may cause a serious loss of time, or of dictating his message, a slow and laborious process. This with the ordinary telephonic apparatus. But if the London friend be the possessor of a Telephonograph, the person answering the call-bell can, if desired to do so, switch the wires into connection with it and start the machinery; and in a very short time the message will be stored up for reproduction when the absent friend returns.

The Telephonograph is the invention of Mr. J. E. O. Kumberg. The message is spoken into the telephone transmitter in the ordinary way, and the vibrations set up by the voice are caused to act upon a recording stylus by the impact of the sound waves at the further end of the wires. In this manner a phonogram is produced on the wax cylinder in the house or office of the person addressed, and it may be read off at leisure. A very sensitive transmitter is employed, and if desired the apparatus can be so arranged that by means of a double-channel tube the words spoken are simultaneously conveyed to the telephone and to an ordinary phonograph, which insures that a record shall be kept of any message sent.

The *Telegraphone*, produced by Mr. Valdemar Poulsen, performs the same functions as the telephonograph, but differs from it in being entirely electrical. It contains no waxen cylinder, no cutting-point; their places are taken respectively by a steel wire wound on a cylindrical drum (each turn carefully insulated from its neighbours) and by a very small electro-magnet, which has two delicate points that pass along the wire, one on either side, resting lightly upon it.

As the drum rotates, the whole of the wire passes gradually between the two points, into which a series of electric shocks is sent by the action of the speaker's voice at the further end of the wires. The shocks magnetise the portion of steel wire which acts as a temporary bridge between the two points. At the close of three and a half minutes the magnet has worked from one end of the wire coil to the other; it is then automatically lifted and carried back to the starting-point in readiness for reproduction of the sounds. This is accomplished by disconnecting the telegraphone from the telephone wires and switching it on to an ordinary telephonic earpiece or receiver. As soon as the cylinder commences to revolve a second time, the magnet is influenced by the series of magnetic "fields" in the wires, and as often as it touches a magnetised spot imparts an impulse to the diaphragm of the receiver, which vibrates at the rate and with the same force as the vibrations originally set up in the distant transmitter. The result is a clear and accurate reproduction of the message, even though hours and even days may have elapsed since its arrival.

As the magnetic effects on the wire coil retain their power for a considerable period, the message may be reproduced many times. As soon as the wire-covered drum is required for fresh impressions, the old one is wiped out by passing a permanent magnet along the wire to neutralise the magnetism of the last message.

Mr. Poulsen has made an instrument of a different type to be employed for the reception of an unusually lengthy communication. Instead of a wire coil on a cylinder, a ribbon of very thin flat steel spring is wound from one reel on to another across the poles of *two* electro-magnets, which touch the lower side only of the strip. The first magnet is traversed by a continuous current to efface the previous record; the second magnetises the strip in obedience to impulses from the telephone wires. The message complete, the strip is run back, and the magnets connected with receivers, which give out loud and intelligent speech as the strip again traverses them. The Poulsen machine makes the transmission of the same message simultaneously through several telephones an easy matter, as the strip can be passed over a series of electro-magnets each connected with a telephone.

THE TELEWRITER.

It is a curious experience to watch for the first time the movements of a tiny Telewriter pen as it works behind a glass window in a japanned case. The pen, though connected only with two delicate wires, appears instinct with human reason. It writes in a flowing hand, just as a man writes. At the end of a word it crosses the t's and dots the i's. At the end of a line it dips itself in an inkpot. It punctuates its sentences correctly. It illustrates its words with sketches. It uses shorthand as readily as longhand. It can form letters of all shapes and sizes.

And yet there is no visible reason why it should do what it does. The japanned case hides the guiding agency, whatever it may be. Our ears cannot detect any mechanical motion. The writing seems at first sight as mysterious as that which appeared on the wall to warn King Belshazzar.

In reality it is the outcome of a vast amount of patience and mechanical ingenuity culminating in a wonderful instrument called the Telewriter. The Telewriter is so named because by its aid we can send our autographs, *i.e.* our own particular handwriting, electrically over an indefinite length of wire, as easily as a telegraph clerk transmits messages in the Morse alphabet. Whatever the human hand does on one telewriter at one end of the wires, that will be reproduced by a similar machine at the other end, though the latter be hundreds of miles away.

The instrument stands about eighteen inches high, and its base is as many inches square. It falls into two parts, the receiver and the transmitter. The receiver is vertical and forms the upright and back portion of the telewriter. At one side of it hangs an ordinary telephone attachment. The transmitter, a sloping desk placed conveniently for the hand, is the front and horizontal portion. The receiver of one station is connected with the transmitter of another station; there being ordinarily no direct communication between the two parts of the same instrument.

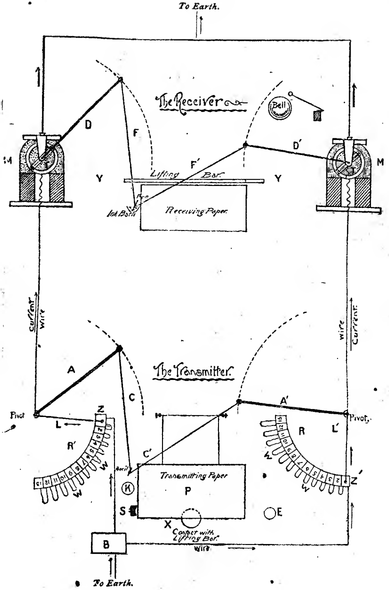
An attempt will be made to explain, with the help of a simple diagram, the manner in which the telautograph performs its duties.

These duties are threefold. In the first place, it must reproduce whatever is written on the transmitter. Secondly, it must reproduce only what is *written*, not all the movements of the hand. Thirdly, it must supply the recording pen with fresh paper to write on, and with fresh ink to write with.

In our diagram we must imagine that all the coverings of the telewriter have been cleared away to lay bare the most essential parts of the mechanism. For the sake of simplicity not all the coils, wires, and magnets having functions of their own are represented, and the drawing is not to scale. But what is shown will enable the reader to grasp the general principles which work the machine.

Turning first of all to the transmitter, we have P, a little platform hinged at the back end, and moving up and down very slightly in front, according as pressure is put on to or taken off it by the pencil. Across it a roll of paper is shifted by means of the lever S, which has other uses as well. To the right of P is an electric bell-push, E, and on the left K, another small button.

The pencil is at the junction of two small bars CC′, which are hinged at their other end to the levers AA′. Any motion of the pencil is transmitted by CC′ to AA′, and by them to the arms LL′, the extremities of which, two very small brushes ZZ′, sweep along the quadrants RR′. This is the first point to observe, that the position of the pencil decides on which sections of the quadrants these little brushes rest, and consequently how much current is to be sent to the distant station. The quadrants are known technically as rheostats, or current-controllers. Each quadrant is divided into 496 parts, separated from each other by insulating materials, so that current can pass from one to the other only by means of some connecting wire. In our illustration only thirteen divisions are given, for the sake of clearness. The dark lines represent the insulation. WW′ are the very fine wire loops connecting each division of the quadrant with its neighbours. If then a current from the


To Earth.
The Receiver
Bell
D
F
M
Y
Lifting Bar
F′
D′
M
Y
Pen
Ink Bath
Receiving Paper
Current
Wire
Wire
Current
The Transmitter
A
C
Pivot
L
Z
R′
W
W
Pencil
C′
Transmitting Paper
P
K
S
X
Contact with Lifting Bar
E
A′
Pivot
R
L′
Z′
W
W
B
Wire
To Earth.

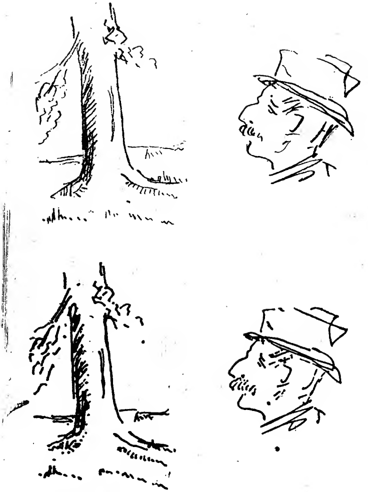
battery B enters the rheostat at division 1 it will have to pass through all these wires before it can reach division 13. The current always enters at 1, but the point of departure from the rheostat depends entirely upon the position of the brushes Z or Z′. If Z happens to be on No. 6 the current will pass through five loops of wire, along the arm L, and so through the main wire to the receiving station; if on No. 13, through twelve loops.

Before going any further we must have clear ideas on the subject of electrical resistance, upon which the whole system of the telewriter is built up. Electricity resembles water in its objection to flow through small passages. It is much harder to pump water through a half-inch pipe than through a one-inch pipe, and the longer the pipe is, whatever its bore, the more work is required. So then, two things affect resistance—*size* of pipe or wire, and *length* of pipe or wire.

The wires WW′ are very fine, and offer very high resistance to a current; so high that by the time the current from battery B has passed through all the wire loops only one-fifteenth or less of the original force is left to traverse the long-distance wire.

The rheostats act independently of one another. As the pencil moves over the transmitting paper, a succession of currents of varying intensity is sent off by each rheostat to the receiving station.

The receiver, to which we must now pay attention, has two arms, DD′, and two rods FF′, corresponding



By kind permission of] [*The Telewriter Co.*

An example of the work done by the Telewriter. The upper sketch shows a design drawn on the transmitter; the lower is the same design as reproduced by the receiving instrument, many miles distant.

[*To face p.* 76.

in size with AA′ and CC′ of the transmitter. The arms DD′ are moved up and down by the coils TT′, which turn on centres in circular spaces at the bend of the magnets MM′. The position of these coils relatively to the magnets depend on the strength of the currents coming from the transmitting station. Each coil strains at a small spiral spring until it has reached the position in which its electric force is balanced by the retarding influence of the spring. One of the cleverest things in the telewriter is the adjustment of these coils so that they shall follow faithfully the motions of the rods LL′ in the transmitter.

We are now able to trace the actions of sending a message. The sender first presses the button E to call the attention of some one at the receiving station to the fact that a message is coming, either on the telephone or on the paper. It should be remarked, by-the-bye, that the same wires serve for both telephone and telewriter, the unhooking of the telephone throwing the telewriter out of connection for the time.

He then presses the lever S towards the left, bringing his transmitter into connection with the distant receiver, and also moving a fresh length of paper on to the platform P. With his pencil he writes his message, pressing firmly on the paper, so that the platform may bear down against an electric contact, X. As the pencil moves about the paper the arms CC′ are constantly changing their angles, and the brushes ZZ′ are passing along the segments of the rheostats.

Currents flow in varying intensity away to the coils TT′ and work the arms DD′, the wires FF′, and the pen, a tiny glass tube.

In the perfectly regulated telewriter the arms AA′ and the arms DD′ will move in unison, and consequently the position of the pen must be the same from moment to moment as that of the pencil.

Mr. Foster Ritchie, the clever inventor of this telewriter, had to provide for many things besides mere slavish imitation of movement. As has been stated above, the pen must record only those movements of the pencil which are essential. Evidently, if while the pencil returns to dot an *i* a long line were registered by the pen corresponding to the path of the pencil, confusion would soon ensue on the receiver; and instead of a neatly-written message we should have an illegible and puzzling maze of lines. Mr. Ritchie has therefore taken ingenious precautions against any such mishap. The platen P on being depressed by the pencil touches a contact, X, which closes an electric circuit through the long-distance wires and excites a magnet at the receiving end. That attracts a little arm and breaks another circuit, allowing the bar Y to fall close to the paper. The wires FF′ and the pen are now able to rest on the paper and trace characters. But as soon as the platen P rises, on the removal of the pencil from the transmitting paper, the contact at X is broken, the magnet at the receiver ceases to act, the arm it attracted falls back and sets up a circuit which causes the bar to spring up again and lift the pen. So that unless you are actually pressing the paper with your pencil, the pen is not marking, though it may be moving.

As soon as a line is finished a fresh surface of paper is required at both ends. The operator pushes the lever S sideways, and effects the change mechanically at his end. At the same time a circuit is formed which excites certain magnets at the receiver and causes the shifting forward there also of the paper, and also breaks the *writing* current, so that the pen returns for a moment to its normal position of rest in the inkpot.

It may be asked: If the wires are passing currents to work the writing apparatus, how can they simultaneously affect the lifting-bar, Y? The answer is that currents of two different kinds are used, a direct current for writing, a vibratory current for depressing the lifting-bar. The *direct* current passes from the battery B through the rheostats RR′ along the wires, through the coils working the arms DD′ and into the earth at the far end; but the *vibratory* current, changing its direction many times a second and so neutralising itself, passes up one wire and back down the other through the lifting-bar connection without interfering with the direct current.

The message finished, the operator depresses with the point of his pencil the little push-key, K, and connects his receiver with the distant transmitter in readiness for an answer.

The working speed of the telewriter is that of the writer. If shorthand be employed, messages can be transmitted at the rate of over 100 words per minute. As regards the range of transmission, successful tests have been made by the postal authorities between Paris and London, and also between Paris and Lyons. In the latter case the messages were sent from Paris to Lyons and back directly to Paris, the lines being connected at Lyons, to give a total distance of over 650 miles. There is no reason why much greater length of line should not be employed.

The telewriter in its earlier and imperfect form was the work of Professor Elisha Gray, who invented the telephone almost simultaneously with Professor Graham Bell. His apparatus worked on what is known as the step-by-step principle, and was defective in that its speed was very limited. If the operator wrote too fast the receiving pen lagged behind the transmitting pencil, and confusion resulted. Accordingly this method, though ingenious, was abandoned, and Mr. Ritchie in his experiments looked about for some preferable system, which should be simpler and at the same time much speedier in its action. After four years of hard work he has brought the rheostat system, explained above, to a pitch of perfection which will be at once appreciated by any one who has seen the writing done by the instrument.

The advantages of the telewriter over the ordinary telegraphy may be briefly summed up as follows:—

Anybody who can write can use it; the need of skilled operators is abolished.

The Telewriter

A record is automatically kept of every message sent.

The person to whom the message is sent need not be present at the receiver. He will find the message written out on his return.

The instrument is silent and so insures secrecy. An ordinary telegraph may be read by sound; but not the telewriter.

It is impossible to tap the wires unless, as is most unlikely, the intercepting party has an instrument in exact accord with the transmitter.

It can be used on the same wires as the ordinary telephone, and since a telephone is combined with it, the subscriber has a double means of communication. For some items of business the telephone may be used as preferable; but in certain cases, the telewriter. A telephone message may be heard by other subscribers; it is impossible to prove the authenticity of such a message unless witnesses have been present at the transmitting end; and the message itself may be misunderstood by reason of bad articulation. But the telewriter preserves secrecy while preventing any misunderstanding. Anything written by it is for all practical purposes as valid as a letter.

We must not forget its extreme usefulness for transmitting sketches. A very simple diagram often explains a thing better than pages of letterpress. The telewriter may help in the detection of criminals, a pictorial presentment of whom can by its means be despatched all over the country in a very short time. And in warfare an instrument flashing back from the advance-guard plans of the country and of the enemy's positions might on occasion prove of the greatest importance.

MODERN ARTILLERY.

THE vast subject of artillery in its modern form, including under this head for convenience' sake not only heavy ordnance but machine-guns and small-arms, can of necessity only be dealt with most briefly in this chapter.

It may therefore be well to take a general survey and to define beforehand any words or phrases which are used technically in describing the various operations.

The employment of firearms dates from a long-distant past, and it is interesting to note that many an improvement introduced during the last century is but the revival of a former invention which only lack of accuracy in tools and appliances had hitherto prevented from being brought into practical usage.

So far back as 1498 the art of *rifling* cannon in straight grooves was known, and a British patent was taken out in 1635 by Rotsipan. The grooves were first made spiral or screwed by Koster of Birmingham about 1620. Berlin possesses a rifled cannon with thirteen grooves dated 1664. But the first recorded use of such weapons in actual warfare was during Louis Napoleon's Italian campaign in 1859, and two years later by General James of the United States Army.

The system of *breech-loading*, again, is as old as the sixteenth century, and we find a British patent of 1741; while the first United States patent was given in 1811 for a flint-lock weapon.

Magazine guns of American production appeared in 1849 and 1860, but these were really an adaptation of the old matchlock revolvers, said to belong to the period 1480–1500. There is one in the Tower of London credited to the fifteenth century, and a British patent of 1718 describes a well-constructed revolver carried on a tripod and of the dimensions of a modern machine-gun. The inventor gravely explains that he has provided round chambers for round bullets to shoot Christians, and square chambers with square missiles for use against the Turks!

Naval guns are of two general types. One is heavy, for use against large armoured vessels or against powerful forts ashore. To this class belong the huge 12-inch and 13.5-inch guns carried by the "Dreadnoughts." These sizes, by the way, refer to the diameter of the bore, or the "calibre," to use the orthodox term. In length they are forty-five or fifty calibres or thereabouts, so that some of them are fifty feet or so in length. If reared up against the ordinary three-story dwelling-house they would reach as high as the roof.

The others are much smaller—say, three, four, or five inches bore. They are for use against such small fry as torpedo boats and destroyers, on whom the larger weapons would be wasted. There are other sizes still, intermediate between these, which are carried by ships of moderate size, but these two, the large heavy gun and the small quick-firing gun (so called because they can throw a large number of shells per minute), represent the main features of naval artillery.

Garrison Artillery consists in the main of similar guns to those of the ships. This is natural, since their function is to protect our shores against attacks from the sea. Their large guns are intended to engage the large weapons of the ships, while their small ones are for use against landing parties or other attempts to rush them, just as the smaller guns of the fleet are to check the attacks of the torpedo craft.

Field Artillery, again, consists of comparatively small guns mounted on carriages, so that they can be hauled about and accompany an army in the field. They go with the infantry, and so are of suitable weight to be hauled about not faster than a trot.

Horse Artillery, on the other hand, are intended to accompany cavalry, and so they are lighter than the field-guns, being capable of moving at a gallop.

Mountain guns, again, are lighter still, and are made in small pieces, which can be fitted together when needed, but none of which are too heavy to be carried on the backs of animals over rugged mountainous country.

Lastly, siege artillery consists of guns which are capable of movement, but heavier than field-guns. They do not need to be moved very fast: all that is necessary is that they should be brought up from the rear with reasonable facility to assist in the attack upon an already beleaguered position. To this class belong the famous 4.7 guns which were so much talked of during the South African war.

There are also used in all these positions, and along with the guns already described, machine-guns, which once set going fire themselves. They send forth a continuous stream of shots, either identical with or but slightly larger than the bullets from a rifle.

The guns already referred to fire *at* an enemy, but there are others which fire over his head, with the idea of dropping their projectile on to him or near him. These are called Howitzers. They are not much, if at all, used on board ship, but in forts and in the field too they have their place. Shorter, and of larger bore than their fellows, they throw the shell upwards, causing it to describe a huge curve in the air, finally plunging downwards on to its objective. Targets for practice with howitzers are not vertical, as is usually the case, but are squares marked out on the ground, and the object of the gunners is to drop the shells inside this square. The difference between the two types of gun may be well illustrated if we think of a fort engaging a ship in battle. With their ordinary guns the soldiers would try to hit and pierce the ship's side; with their howitzers they would try to drop high explosive shells upon its deck.

What is the chief feature of the howitzer is strenuously avoided in all other guns. The latter try to fire with what is termed a flat trajectory, which means that they endeavour to get the projectile to move in as straight a line as possible. This much-sought result can never be entirely attained. The path of a projectile, whether rifle bullet or naval shell, is always, and must always be, a curve. Every moving body, as Sir Isaac Newton discovered, tries to keep on in a straight line. But equally persistent is the force of gravity, which pulls everything downwards. The air, too, has its say in the matter, doing its little best to prevent the rushing projectile from rudely pushing it aside, and succeeding sooner or later in retarding its passage very considerably. Thus we may consider the journey of a projectile as a continual struggle between forces. Its velocity causes it to press forward, the air and gravity acting in alliance try to stop it. It leaves the gun with a certain velocity: gravity pulls it down. Now, it is a curious thing, but gravity has just the same effect upon a moving body as upon a stationary one. If a bullet be left unsupported in the air it falls to the ground. If it be fired from a rifle in a horizontal direction, and from the same height, it will fall to the ground in the same time.

A bullet dropped from a window about sixteen feet high will reach the ground in a second. If fired from the same window in a horizontal direction at the speed of 1000 yards per second, it will also reach the ground in a second. In the latter case, however, it will fall nearly a thousand yards away instead of close under the window.

If it be fired at the rate of 2000 yards per second, it will still reach the ground in one second, but the point where it falls will be nearer 2000 yards away.

Now it is clear that when it goes the 2000 yards before touching the ground, its path is much more nearly straight than when it only goes 1000. Therefore the faster it travels the flatter the "trajectory."

But in the cases which we have just been imagining we have ignored one important factor in the situation. A bullet shot forth at the rate of 1000 yards per second will not travel 1000 yards in a second, for it will gradually lose its speed. It tries hard to maintain it, but the resistance of the air acts as a brake and gradually slows it down. It still falls to the ground in a second, but the point is so much the nearer to the starting-point. Consequently the resistance of the air is such as to make the trajectory more rounded.

To sum up, therefore, the maker of guns tries to make his projectile travel with a high initial velocity, and to arrange matters so that the air shall have the minimum of effect upon it. In these two requirements we shall find the source of many of the modern inventions in artillery.

In the old days guns were smooth in the bore, and the projectiles were round balls. Moreover, the balls were a poor fit in the gun. The result was that the expanding gases which form the explosion largely escaped past the cannon ball without doing their share in pushing it. Poor velocity was the result. Materials for making guns were weak, too, and so powerful explosions were not possible. As recently as Crimean times guns were made of cast iron. The wonderful invention of cheap cast steel by Sir Henry Bessemer was the result of a desire to find a better material for guns. The process has gone on since his time, with the result that to-day the most wonderful alloys of iron, known under the names of various kinds of steel, have been discovered for the manufacture of guns. The shape of the projectiles has been altered, too, from spherical to elongated. The idea of this is to give greater weight, and therefore greater hitting power, without increasing the resistance of the air. A round ended or pointed cylinder of any given diameter has no more resistance to encounter from the air than a ball of the same diameter, yet it may be several times as heavy. That is only true, however, so long as it moves point first. To ensure this it must be given a spin. When that is done it keeps point first, just as and for the same reason that a top remains point downwards so long as it is rotating.

To obtain the spinning motion the barrel of the gun is rifled—that is to say, it has grooves cut inside it, which form the threads of a screw. The shell, too, has one or more rings of soft copper round it—driving bands they are called—and these serve a double purpose, for they make a perfect fit against the barrel, preventing the escape of the gases referred to just now, and they catch in the grooves and carry the shell round and round as it moves down the gun. Thus the desired object is largely achieved, great velocity with the minimum resistance from the air.

It remains to be explained why flatness of trajectory is so much sought after. It is because it increases the "danger zone." A shot up in the air cannot hit anyone. Take the case of men, whom we will suppose to be six feet tall. Until it reaches a level of at most six feet from the ground a shot cannot hit them. And when it strikes the ground it cannot hit them. Consequently the shot must be made to travel as far as possible between the moment when it is within six feet and the moment when it strikes the ground. That distance, whatever it may be, is the "danger-zone"—the space, that is, over which it is dangerous for a man to be. Now it is easy to see that the steeper the angle at which the shot falls the smaller will be this zone. The shot must therefore be made to approach the ground as nearly as possible to the horizontal; then the danger zone will be the greatest possible.

RIFLES.

Up to the middle of last century our soldiers were armed with the flint-lock musket known as "Brown Bess," a smooth-bore barrel ¾-inch in diameter, thirty-nine inches long, weighing with its bayonet over eleven pounds. The round leaden bullet weighed an ounce, and had to be wrapped in a "patch" or bit of oily rag to make it fit the barrel and prevent windage; it was then pushed home with a ramrod on to the powder-charge, which was ignited by a spark passing from the flint into a priming of powder. How little its accuracy of aim could be depended upon, however, is proved by the word of command when advancing upon an enemy, "Wait till you see the whites of their eyes, boys, before you fire!"

In the year 1680 each troop of Life Guards was supplied with eight rifled carbines, a modest allowance, possibly intended to be used merely by those acting as scouts. After this we hear nothing of them until in 1800 the 95th Regiment received a 20-bore muzzle-loading rifle, exchanged about 1835 for the Brunswick rifle firing a spherical bullet, an improvement that more than doubled its effective range. The companies so armed became known as the Rifle Brigade. At last, in 1842, the old flint-lock was superseded for the whole army by the original percussion musket, a smooth-bore whose charge was exploded by a percussion cap made of copper. [That this copper had some commercial value was shown by the rush of "roughs" to Aldershot and elsewhere upon a field-day to collect the split fragments which strewed the ground after the troops had withdrawn.]

Soon afterward the barrel was rifled and an elongated bullet brought into use. This missile was pointed in front, and had a hollowed base so contrived that it expanded immediately the pressure of exploding gases was brought to bear on it, and thus filled up the grooves, preventing any windage. The one adopted by our army in the year 1852 was the production of M. Minié, a Frenchman, though an expanding bullet of English invention had been brought forward several years before.

Meanwhile the Prussians had their famous needle-gun, a breech-loading rifled weapon fired by a needle attached to a sliding bolt; as the bolt is shot forward the needle pierces the charge and ignites the fulminate by friction. This rifle was used in the Prusso-Austrian war of 1866 some twenty years after its first inception, and the French promptly countered it by arming their troops with the Chassepôt rifle, an improved edition of the same principle. A piece which could be charged and fired in any position from five to seven times as fast as the muzzle-loader, which the soldier had to load standing, naturally caused a revolution in the infantry armament of other nations.

The British Government, after long and careful consideration, decided in 1864 upon using breech-loading rifles. Till a more perfect weapon could be obtained the Enfields were at a small outlay converted into breech-loaders after the plans of Mr. Snider, and were henceforward known as Snider-Enfields. Eventually—as the result of open competition—the Martini-Henry rifle was produced by combining Henry's system of rifling with Martini's mechanism for breech-loading. This weapon had seven grooves with one turn in twenty-two inches, and weighed with bayonet 10 lb. 4 oz. It fired with great accuracy, the trajectory having a rise of only eight feet at considerable distances, so that the bullet would not pass over the head of a cavalry man. Twenty rounds could be fired in fifty-three seconds.

Now in the latter years of the century all these weapons have been superseded by magazine rifles, *i.e.* rifles which can be fired several times without recourse to the ammunition pouch. They differ from the revolver in having only one firing chamber, into which the cartridges are one by one brought by a simple action of the breech mechanism, which also extracts the empty cartridge-case. The bore of these rifles is smaller and the rifling sharper; they therefore shoot straighter and harder than the large bore, and owing to the use of new explosives the recoil is less.

The French *Lebel* magazine rifle was the pioneer of all now used by European nations, though a somewhat similar weapon was familiar to the Americans since 1849, being first used during the Civil War. The Henry rifle, as it was called, afterwards became the Winchester.

The German army rifle is the *Mauser*, so familiar to us in the hands of the Boers during the South African War—loading five cartridges at once in a case or "clip" which falls out when emptied. The same rifle has been adopted by Turkey, and was used by the Spaniards in the late Spanish-American War.

The Austrian *Mannlicher*, adopted by several continental nations, and the Krag-Jorgensen now used in the north of Europe and as the United States army weapon, resemble the Mauser in most particulars. Each of these loads the magazine in one movement with a clip.

The *Hotchkiss* magazine rifle has its magazine in the stock, holding five extra cartridges pushed successively into loading position by a spiral spring.

The British Government still use a Lee-Enfield rifle, but of a much improved type. The magazine holds ten cartridges.

An important and interesting feature of a rifle is the sights. The front sight consists of a little vertical projection of some sort, while the back sight may be a V-shaped groove or a tiny hole. The latter is the better, for it is impossible to get three objects at different distances in focus at the same time—it must be remembered that the eye needs to focus just as a camera does. Consequently one or two out of the three things must be blurred. By placing the eye to a small hole, say, a twentieth of an inch in diameter, and looking through it instead of at it, one of the three is practically done away with, so far as seeing is concerned; while the other two, being both at some distance, can be seen fairly well with the eye at the same focus. The marksman, therefore, need only look *through* the hole which forms the back sight and see if the foresight and the distant object appear in line.

It may be interesting to enumerate the diameters or calibre of the various rifles:

Dutch, Italian, Roumanian, and Greek "Mannlicher"	.256 inches
Spanish "Mauser"	.276 „
Russian and U.S.A.	.300 „
Belgian and Turkish "Mausers"	.301 „
British "Lee-Enfield" and Canadian "Ross"	.303 „
German "Mauser"	.311 „
Austrian and Bulgarian "Mannlichers," French "Lebel," and Danish "Krag-Jorgensen"	.315 „

The above are given on the authority of the well-known firm of gun-makers, The Birmingham Small Arms Co., whose cycle fittings most of us know if we cannot speak from experience of their guns. This company also give some wonderfully interesting facts as to the care which has to be exercised in order to produce really good rifles. For instance:

The barrel is inspected or tested no less than ten times during the course of manufacture. A thousandth of an inch would be regarded as a fatal error, rendering the part useless. Seven hundred gauges are used to check the sizes of the parts as they are made, and these gauges are true to within a ten-thousandth of an inch.

The action-body of a Lee-Enfield rifle weighs nearly 5 lb. in the rough: before it is finished it has to undergo 149 separate operations, whereby its weight is reduced down to a pound and an eighth only. And it is only one of the parts. The same sort of thing is true of many others.

To our neighbours across the Channel the credit also belongs of introducing *smokeless powder*, now universally used; that of the Lee-Metford being "cordite." To prevent the bullets flattening on impact they are coated with a hard metal such as nickel and its alloys. If the nose is soft, or split beforehand, a terribly enlarged and lacerated wound is produced; so the Geneva Convention humanely prohibited the use of such missiles in warfare.

Before quitting this part of our subject it is as well to add a few words about *pistols*.

These have passed through much the same process of evolution as the rifle, and have now culminated in the many-shotted *revolver*.

During the period 1480–1500 the matchlock revolver is said to have been brought into use; and one attributed to this date may be seen in the Tower of London.

Two hundred years ago, Richards, a London gunsmith, converted the ancient wheel-lock into the flint-lock; he also rifled his barrel and loaded it at the breech. The Richards weapon was double-barrelled, and unscrewed for loading at the point where the powder-chamber ended; the ball was placed in this chamber in close contact with the powder, and the barrel rescrewed. The bullet being a soft leaden ball was forced, when the charge was fired, through the rifled barrel with great accuracy of aim.

The percussion cap did not oust the flint-lock till less than a century ago, when many single-barrelled pistols, such as the famous Derringer, were produced; these in their turn were replaced by the revolver which *Colt* introduced in 1836–1850. Smith and Wesson in the early sixties improved upon it by a device for extracting the empty cartridges automatically. Livermore and Russell of the United States invented the "clip," containing several cartridges; but the equally well-known *Winchester* has its cartridges arranged in a tube below the barrel, whence a helical spring feeds them to the breech as fast as they are needed.

At the present time each War Department has its own special service weapon. The German *Mauser* magazine-pistol for officer's use fires ten shots in ten seconds, a slight pressure of the trigger setting the full machinery in motion; the pressure of gas at each explosion does all the rest of the work—extracts and ejects the cartridge case, cocks the hammer, and presses springs which reload and close the weapon, all in a fraction of a second. The *Mannlicher* is of the same automatic type, but its barrel moves to the front, leaving space for a fresh cartridge to come up from the magazine below, while in the Mauser the breech moves to the rear during recoil. The range is half a mile. The cartridges are made up in sets of ten in a case, which can be inserted in one movement.

MACHINE-GUNS.

Intermediate between hand-borne weapons and artillery, and partaking of the nature of both, come the machine-guns firing small projectiles with extraordinary rapidity.

Since the United States made trial of Dr. Gatling's miniature battery in the Civil War (1862–1865), invention has been busy evolving more and more perfect types, till the most modern machine-gun is a marvel of ingenuity and effectiveness.

The *Gatling* machine-gun, which has been much improved in late years by the Accles system of "feed," and is not yet completely out of date, consists of a circular series of ten barrels—each with its own lock—mounted on a central shaft and revolved by a suitable gear. The cartridges are successively fed by automatic actions into the barrels, and the hammers are so arranged that the entire operation of loading, closing the breech, firing and withdrawing the empty cartridge-cases (which is known as their "longitudinal reciprocating motion") is carried on while the locks are kept in constant revolution, along with the barrels and breech, by means of a hand-crank. One man places a feed-case filled with cartridges into the hopper, another turns the crank. As the gun is rotated the cartridges drop one by one from the feed-cases into the grooves of the carrier, and its lock loads and fires each in turn. While the gun-revolves further the lock, drawing back, extracts and drops the empty case; it is then ready for the next cartridge.

In action five cartridges are always going through some process of loading, while five empty shells are in different stages of ejection. The latest type, fitted with an electro-motor, will fire at the *rate* of one thousand rounds per minute, and eighty rounds have actually been fired within ten seconds! It is not, however, safe to work these machine-guns so fast, as the cartridges are apt to be occasionally pulled through unfired and then explode among the men's legs. The automatic guns, on the contrary, as they only work by the explosion, are free from any risk of such accidents.

The feed-drums contain 104 cartridges, and can be replaced almost instantly. One drumful can be discharged in 5¼ seconds. The small-sized Gatling has a drum-feed of 400 cartridges in sixteen sections of twenty-five each passed up without interruption.

'The gun is mounted for use so that it can be pointed at any angle, and through a wide lateral range, without moving the carriage.

The Gardner.—The Gatling, as originally made, was for a time superseded by the *Gardner*, which differed from it in having the barrels (four or fewer in number) fixed in the same horizontal plane. This was worked by a rotatory handle on the side of the gun. The cartridges slid down a feed-case in a column to the barrel, where they were fired by a spring acting on a hammer.

The Nordenfelt.—Mr. Nordenfelt's machine-gun follows this precedent; its barrels—10, 5, 4, 2, or 1 in number—also being arranged horizontally in a strong, rigid frame. Each barrel has its own breech-plug, striker, spring, and extractor, and each fires independently of the rest, so that all are not out of action together. The gun has a swivelled mount easily elevated and trained, and the steel frames take up the force of the discharge. In rapid firing one gunner can work the firing-handle while another lays and alters the direction. The firing is operated by a lever working backwards and forwards by hand, and the gun can be discharged at the rate of 600 rounds per minute.

The Hotchkiss.—The Hotchkiss gun, or revolving cannon, is on a fresh system, that of intermittent rotation of the barrels without any rotation of breech or mechanism. There is only one loading piston, one spring striker, and one extractor for all the barrels. The shock of discharge is received against a massive fixed breech, which distributes it to the whole body.

Like the *Nordenfelt*, however, it can be dismounted and put together again without the need of tools. The above pattern throws 1 lb. projectiles.

The Maxim.—Differing from all these comes the *Maxim* gun, so much in evidence now with both land and sea service. It is made up of two portions:—

(1) *Fixed;* a barrel-casing, which is also a water-jacket, and breech-casing.

(2) *Recoiling:* a barrel and two side plates which carry lock and crank.

This recoiling portion works inside the fixed.

The gun is supplied with ammunition by a belt holding 250 cartridges passing through a feed-block on the top. Its mechanism is worked *automatically;* first by the explosion of the charge, which causes the barrel to recoil backwards and extends a strong spring which, on reasserting itself, carries it forwards again. The recoiling part moves back about an inch, and this recoil is utilised by bringing into play mechanism which extracts the empty cartridge-case, and on the spring carrying the barrel forward again moves a fresh one into position. Under the barrel casing is the ejector tube through which the empty cartridge-cases are ejected from the gun.

The rate of fire of the Maxim gun is 600 rounds per minute. Deliberate fire means about 70 rounds per minute; rapid fire will explode 450 rounds in the same time. As the barrel becomes very hot in use the barrel-casing contains seven pints of water to keep it cool. About 2000 rounds can be fired at short intervals; but in continuous firing the water boils after some 600 rounds, and needs replenishing after about 1000. A valved tube allows steam, but not water to escape.

The operator works this gun by pressing a firing-lever or button. After starting the machine he merely sits behind the shield, which protects him from the enemy, directing it, as it keeps on firing automatically so long as the bands of cartridges are supplied and a finger held on the trigger or button. By setting free a couple of levers with his left hand, and pressing his shoulder against the padded shoulder-piece, he is able to elevate or depress, or train the barrel horizontally, without in any way interfering with the hail of missiles.

We use two sizes, one with .45 bore for the Navy, which takes an all-lead bullet weighing 480 grains, and the other with .303 bore, the ordinary nickel-coated rifle bullet for the Army. But as the Maxim gun can be adapted to every rifle-calibre ammunition it is patronised by all governments.

The gun itself weighs 56 lbs., and is mounted for use in various ways: on a tripod, a field stand, or a field carriage with wheels. This carriage has sixteen boxes of ammunition, each containing a belt of 250 cartridges, making 4000 rounds altogether. Its total weight is about half a ton, so that it can be drawn by one horse, and it is built for the roughest cross-country work. A little machine, which can be fixed to the wheel, recharges the belts with cartridges by the working of a handle.

For ships the Maxim is usually mounted on the roofs of the large turrets, or it can be clamped to the bulwark of the deck or the military "top" on the mast.

But there is a most ingenious form of parapetmounting, known as the garrison mount, which turns the Maxim into a "disappearing gun," and can be used equally well for fortress walls or improvised entrenchments. The gun is placed over two little wheels on which it can be run along by means of a handle pushed behind in something the fashion of a lawn-mower. Arrived at its destination, the handle, which is really a rack, is turned downwards, and on twisting one of the wheels the gun climbs it by means of a pinion-cog till it points over the wall, to which hooks at the end of two projecting bars firmly fix it, the broadened end of the handle being held by its weight to the ground. It is locked while in use, but a few turns of the wheel cause it to sink out of sight in as many seconds.

The rifle-calibre guns may also be used as very light horse artillery to accompany cavalry by being mounted on a "galloping carriage" drawn by a couple of horses, and with two seats for the operators. The carriage conveys 3000 rounds, and the steel-plated seats turn up and form shields during action.

It is interesting to notice that an extra light form of the gun is made which may be carried strapped on an infantryman's back and fired from a tripod. Two of these mounted on a double tricycle can be propelled at a good pace along a fairly level road, and the riders dismounting have, in a few moments, a valuable little battery at their disposal.

The *Pom-pom*, of which we heard so much in the South African war, is a large edition of the Maxim automatic gun with some differences in the system. Its calibre is 1½ inches. Instead of bullets it emits explosive shells 1 lb. in weight, fitted with percussion fuses which burst them into about twelve or fourteen pieces. The effective range is up to 2000 yards, and it will carry to 4000 yards. An improved *Pom-pom* recently brought out hurls a 1¼ lb. shell with effect at a mark 3000 yards away, and as far as 6000 yards before its energy is entirely exhausted. The muzzle velocity of this weapon is 2350 feet a second as against the 1800 feet of the older pattern. They both fire 300 rounds a minute.

The *Colt* automatic gun is an American invention whose automatic action is due to explosion of the charge, not to recoil. The force by which the motions of firing, extracting, and loading are performed is derived from the powder-gases, a portion of which—passing through a small vent in the muzzle—acts by means of a lever on the mechanism of the gun.

This is also in two parts: (*a*) *barrel*, attached to (*b*) breech-casing, in which gear for charging, firing, and ejecting is contained. The barrel, made of a strong alloy of nickel, has its cartridges fed in by means of belts coiled in boxes attached to the breech-casing, the boxes moving with the latter so that the movements of the gun do not affect it. These boxes contain 250 cartridges each and are easily replaced.

The feed-belt is inserted, and the lever thrown down and moved backward—once by hand—as far as it will go; this opens the breech and passes the first cartridge from the belt to the carrier. The lever is then released and the spring causes it to fly forward, close the vent, and transfer the cartridge from the carrier to the barrel, also compressing the mainspring and opening and closing the breech.

On pulling the trigger the shot is fired, and after the bullet has passed the little vent, but is not yet out of the muzzle, the force of the expanding gas, acting through the vent on the piston, sets a gas-lever in operation which acts on the breech mechanism, opens breech, ejects cartridge-case, and feeds another cartridge into the carrier. The gas-lever returning forces the cartridge home in the barrel and closes and locks the breech.

The hammer of the gun acts as the piston of an air-pump, forcing a strong jet of air into the chamber, and through the barrel, thus removing all unburnt powder, and thoroughly cleansing it. The metal employed is strong enough to resist the heaviest charge of nitro-powder, and the accuracy of its aim is not disturbed by the vibrations of rapid fire. It does not heat fast, so has no need of a water-jacket, any surplus heat being removed by a system of radiation.

The bore is made of any rifle calibre for any small-arm ammunition, and is fitted with a safety-lock. Four hundred shots per minute can be fired.

The gun consists altogether of ninety-four pieces, but the working-pieces, *i.e.* those only which need be separated for cleaning, &c., when in the hands of the artilleryman, are less than twenty. It can be handled in action by one man, the operation resembling that of firing a pistol.

The machine weighs 40 lbs., and for use by cavalry or infantry can be mounted on the *Dundonald Galloping Carriage.* The ammunition-box, containing 2000 rounds ready for use, carries the gun on its upper side, and is mounted on a strong steel axle. A pole with a slotted end is inserted into a revolving funnel on the bend of the shaft, the limbering-up being completed by an automatic bolt and plug.

The gun-carriage itself is of steel, with hickory wheels and hickory and steel shafts, detachable at will. The simple harness suits any saddled cavalry horse, and the shafts work in sockets behind the rider's legs. Its whole weight with full load of ammunition is under four hundredweight.

HEAVY ORDNANCE.

As with rifles and the smaller forms of artillery, so also with heavy ordnance, the changes and improvements within the last fifty years have been greater than those made during the course of all the previous centuries.

These changes have affected alike not only the materials from which a weapon is manufactured, the relative size of calibre and length of bore, the fashion of mounting and firing, but also the form and weight of the projectile, the velocity with which it is thrown and even the substances used in expelling it from the gun.

Compare for a moment the old cast-iron muzzle-loaders, stubby of stature, which Wellington's bronzed veterans served with round cannon balls, well packed in greasy clouts to make them fit tight, or with shell and grape shot, throughout the hard-fought day of Waterloo, from a distance which the chroniclers measure by *paces*, so near stood the opposing ranks to one another.

Or stand in imagination upon one of Nelson's stately men-o'-war and watch the grimy guns' crews, eight or ten to each, straining on the ropes. See the still smoking piece hauled inboard, its bore swabbed out to clean and cool it, then recharged by the muzzle; home go powder, wad, and the castor full of balls or the chain shot to splinter the enemy's masts, rammed well down ere the gun is again run out through the port-hole. Now the gunner snatches the flaming lintstock and, signal given, applies it to the powder grains sprinkled in the touch-hole. A salvo of fifty starboard guns goes off in one terrific broadside, crashing across the Frenchman's decks at such close quarters that in two or three places they are set on fire by the burning wads. Next comes a cry of "Boarders!' and the ships are grappled as the boarding-party scrambles over the bulwarks to the enemy's deck, a brisk musket-fire from the crowded rigging protecting their advance; meanwhile the larboard guns, with their simultaneous discharge, are greeting a new adversary.

Such was war a century ago. Compare with it the South African Campaign where the range of guns was estimated in *miles*, and after a combat lasting from morn to eve, the British general could report: "I do not think we have seen a gun or a Boer all day."

The days of hand-to-hand fighting have passed, the mêlée in the ranks may be seen no more; in a few years the bayonet may be relegated to the limbo of the coat-of-mail or the cast-iron culverin. Yet the modern battle-scene bristles with the most death-dealing weapons which the ingenuity of man has ever constructed. The hand-drawn machine-gun discharges in a couple of minutes as many missiles as a regiment of Wellington's infantry, with a speed and precision undreamt of by him. The quick-firing long-range naval guns now in vogue could annihilate a fleet or destroy a port without approaching close enough to catch a glimpse of the personnel of their opponents. The deadly torpedo guards our waterways more effectually than a squadron of ships.

All resources of civilisation have been drawn upon, every triumph of engineering secured, to forge such weapons as shall strike the hardest and destroy the most pitilessly. But strange and unexpected the result! Where we counted our battle-slain by thousands we now mourn over the death of hundreds; where whole regiments were mown down our ambulances gather wounded in scattered units. Here is the bright side of modern war.

The muzzle-loading gun has had its day, a very long day and a successful one. Again and again it has reasserted itself and ousted its rivals, but at last all difficulties of construction have been surmounted and the breech-loader has "come to stay."

Until quite recently our services contained a large number of muzzle-loading guns, many of them built at quite a recent period, and adapted as far as possible to modern requirements. So to these we will first turn our attention.

The earliest guns were made of cast-iron, but this being prone to burst with a large charge, bronze, brass, and other tougher materials were for a long time employed. Most elaborately chased and ornamented specimens of these old weapons are to be seen in the Tower, and many other collections.

In the utilitarian days of the past century cheapness and speed in manufacture were more sought after than show. Iron was worked in many new ways to resist the pressure of explosion.

Armstrong of Elswick conceived the idea of building up a barrel of *coiled* iron by joining a series of short welded cylinders together, and closing them by a solid forged breech-piece. Over all, again, wrought-iron coils were shrunk. Subsequently he tried a solid forged-iron barrel bored out to form a tube. Neither make proving very satisfactory, steel tubes were next used, but were too expensive and uncertain at that stage of manufacture. Again coiled iron was called into requisition, and Mr. Frazer of the Royal Gun Factory introduced a system of double and triple coils which was found very successful, especially when a thin steel inner tube was substituted for the iron one (1869).

All these weapons were rifled, so that there was of necessity a corresponding difference in the projectile employed. Conical shells being used, studs were now placed on the body of the shell to fit into the rifling grooves, which were made few in number and deeply cut. This was apt to weaken the bore of the gun; but on the other hand many studs to fit into several shallow grooves weakened the cover of the shells.

Various modifications were tried, and finally a gas-check which expands into the grooves was placed at the base of the shell.

The muzzle-loader having thus been turned into a very efficient modern weapon the next problem to be solved was how to throw a projectile with sufficient force to penetrate the iron and steel armour-plates then being generally applied to war-ships. "Build larger guns" was the conclusion arrived at, and presently the arsenals of the Powers were turning out mammoth weapons up to 100 tons, and even 110 tons in weight with a calibre of 16 inches and more for their huge shells. Then was the mighty 35-ton "Woolwich Infant" born (1872), and its younger but still bigger brothers, 81 tons, 16-inch bore, followed by the Elswick 100-ton giants, some of which were mounted on our defences in the Mediterranean. But the fearful concussion of such enormous guns when fired in action on board ship injured the superstruction, and even destroyed the boats, and the great improvements made in steel both for guns and armour soon led to a fresh revolution. Henceforward instead of mounting a few very heavy guns we have preferred to trust to the weight of metal projected by an increased number of smaller size, but much higher velocity. And these guns are the quick-firing breech-loaders.

There was thus a sudden drop in the size of big guns from the large muzzle-loaders mentioned at the top of this page. For several years up to about 1910 the British Navy had as its largest weapon the 12-inch gun, which was only about two-thirds the weight of the old "81," and had a projectile of just half the weight. Yet it could hit harder and hit oftener, so that for fighting purposes it was much superior.

This power to hit hard and quickly is due to several things. In the first place, the method of loading the gun through a door, as we might almost call it, at the breech or inner end, instead of through the muzzle, enables the gun to be loaded, fired, cleaned out, and ready for loading again, in much less time than was possible before. That largely accounts for the rapidity.

The greater speed given to the projectile, and the consequently more powerful blow which it can give, is largely due to improved methods of making the gun. It is much longer than the older one. So long as it is inside the gun the projectile is being pushed by the expanding gases which result from the explosion. The longer the gun, therefore, the longer time has the shell for getting up its speed.

The change from the muzzle-loader to the more modern gun occurred, too, just at the time when wonderful improvements were taking place in the manufacture and manipulation of metals, and in the machines for working metals. Consequently the newer guns are much more perfectly made. Steel castings of great size can now be made quite easily, and the addition of chrome and nickel to the steel gives an alloy of such hardness and toughness as to be quite a different material from that which used to be employed. Thoroughly scientific ways have been discovered, too, whereby the metal can be hardened by sudden cooling, or toughened by gradual cooling after long heating.

The size of guns is growing again, but the 12-inch naval gun may be taken as the type of the modern weapon, and a description of it will to a great extent do for them all.

There are first of all two tubes of steel, one inside the other. Around the outer one is wound a hundred and thirty miles or so of wire, or, more strictly, tape, of high-tensile steel capable of supporting enormous weights. Over this layer of wire comes another tube, and another over that. The several tubes are turned and bored to size with the utmost exactness, and being expanded by heat the outer ones are forced over the inner ones, the subsequent contraction on cooling causing them to grip tightly. This is called shrinking them on.

All the large guns in the British services are made in this way, the belief being that the wire renders them more reliable. Should a solid tube crack, the crack will get worse and worse, but if a strand or two of the wire be fractured there is little weakening; it causes but a slight weakening of the gun, and there is no tendency for it to get worse.

The smaller guns, however, are made of solid tubes shrunk on one over another.

The breech mechanism of a modern gun of large size is a most marvellous piece of workmanship. Armstrong's, Vickers', Krupp's, and other makers have each their own designs, but they are all alike in purpose. They must have a plug or door, usually called the breech-block, which can be opened in a moment, closed equally quickly, strong enough and firmly fixed enough to resist the terrific force of the explosion, yet smooth, so smooth in its working as to cause no jarring or vibration as it is opened or closed.

Provision is made, too, to prevent the awful calamity which would result from the charge being fired while the breech-block is open. The firing mechanism is interlocked with the breech-block, so that it can only work when the breech-block is closed and properly secured. Then, and only then, can the gun be fired. This can be done, by the way, either by an electric spark or by percussion.

The modern field-gun is mounted upon a carriage made almost entirely of steel, the wheels only being of wood. It is fitted also with a spring buffer which takes up the recoil without causing the carriage to move at all. Not long ago the carriage ran back after every shot, and had to be replaced for the next one. Now, however, the gun itself can slide back, irrespective of the carriage, as much as four feet, the spring immediately bringing it back to its former position ready for the next shot. Thus shot after shot can be fired without having to relay the gun, and as many as twenty aimed shots per minute can be fired with ease.

Howitzers, of course, have carriages which enable them to be pointed upwards at a high angle, as high as fifty degrees, and a form of howitzer known as mortars are so arranged that they can be pointed even higher than that.

The modern battleship of the Dreadnought type has ten or twelve of the largest guns. They are usually placed in pairs on turntables covered with a complete shield of armour plate, there being but a small opening through which the muzzles project. The turret, as the turntable with its armour is called, stands within a circular wall of the thickest armour plate called a barbette, so that the guns and the men working them are as far as possible shielded. The guns are trained or pointed by turning the whole turret, while they are elevated or depressed by mechanism inside the turret. Breech-blocks are opened and closed by power, air-jets blow out the dust from the guns before they are loaded. Shells and "powder" come up from the magazines below on power-driven hoists—indeed, they are even pushed into the breech by power. Hence the large guns of to-day can be served more quickly than the tiny weapons of Nelson's time.

The medium-sized guns which used to appear on battleships are not fitted now. They have been displaced by the greater number of large ones.

Cruisers of the Dreadnought type have eight of the large guns. Indeed, they only differ from the battleships in that they have two less large guns and thinner armour, the weight so saved being put into engine power, so that they have great speed.

All manner of guns are found, however, on the smaller cruisers, varying from the fairly big gun down to the little spit-fire intended to drive off torpedo boats should they be audacious enough to try to torpedo the larger craft. Practically all ships have small guns, such as the well-known 4.7, for this purpose.

Submarines even carry a small gun or two nowadays.

The airship, whether of the steerable balloon or the aeroplane type, scarcely needs a gun, for it can drop its projectile from above, and gravity will do what normally needs an explosive, but the gun is needed to fight the air-ship.

These are light, firing a projectile of from 14 to 40 lbs., and are so mounted that they can be pointed almost vertically. When fired at an elevation of forty-five degrees a range of about eight miles is possible. Special shells, too, are made, having a light at the back which becomes ignited as soon as the shell leaves the gun, and which, passing through a balloon, would explode the gas with which it is filled.

Some of the guns for this purpose are fixed upon motor-cars, for the quickness of the airship necessitates its attacker being very nimble too.

For the defence of harbours, dockyards, forts, &c., from attack from above, the guns are sunk in pits in the ground, covered over with bomb-proof roofs through which "port holes" are made, from which the concealed and protected guns can fire upwards.

The searchlight has taken the place of all those former inventions thrown from guns, such as ground-light balls, or parachute lights with a time-fuse which burst in the air and remained suspended, betraying the enemy's proceedings.

In like manner the linked chain and "double-headed" shot, the "canister"—iron balls packed in thin iron or tin cylinders which would travel about 350 yards—the "carcasses" filled with inflammable composition for firing ships and villages, are as much out of date as the solid round shot or cannon-ball.

Young Shrapnell's invention a century ago of the form of shell that bears his name, a number of balls arranged in a case containing also a small bursting-charge fired either by percussion or by a time-fuse, has practically replaced them all. Thrown with great precision of aim its effective range is now up to 5000 yards. A 15-pounder shrapnell shell, for instance, contains 192 bullets, and covers several hundred yards with the scattered missiles flying with extreme velocity.

Common shell, from 2½ to 3 calibres long, contains an explosive only. Another variety is segment shell, made of pieces built up in a ring with a bursting charge in the centre which presently shatters it.

The Palliser shell has a marvellous penetrating power when used against iron plates. But, *mirabile dictu!* experiments prove that a soft cap added externally enables a projectile to pierce with ease armour which had previously defied every attack.

EXPLOSIVES.

Half a century ago gunpowder was still the one driving power which started the projectile on its flight. It is composed of some 75 parts of saltpetre or nitrate of potash, 15 parts of carefully prepared charcoal, and 10 parts of sulphur. This composition imprisons a large amount of oxygen for combustion, and is found to act most successfully when formed into rather large prismatic grains.

On the abolition of the old flint-lock its place was taken by a detonating substance enclosed in a copper cap, and some time later inventors came forward with new and more powerful explosives to supersede the use of gunpowder.

By treating cotton with nitric and sulphuric acid reaction *gun-cotton* was produced; and a year later glycerine treated in the same manner became known to commerce as *nitro-glycerine*. This liquid form being inconvenient to handle, some inert granular substance such as infusorial earth was used to absorb the nitro-glycerine, and *dynamite* was the result.

The explosion of gun-cotton was found to be too sudden and rapid for rifles or cannon; it was liable to burst the piece instead of blowing out the charge. In order to lessen the rapidity of its ignition ordinary cotton was mixed with it, or its threads were twisted round some inert substance.

When repeating-rifles and machine-guns came into general use a smokeless powder became necessary. Such powders as a rule contain nitro-cellulose (gun-cotton) or nitro-glycerine, or both. These are combined into a plastic, gluey composition, which is then made up into sticks or pellets of various shapes, and usually of large size to lessen the extreme rapidity of their combustion. Substances such as tan, paraffin, starch, bran, peat, &c., &c., and many mineral salts, are used in forming low explosives from high ones.

To secure complete combustion some of the larger pellets are made with a central hole, or even pierced by many holes, so that the fire penetrates the entire mass and brings out all its explosive qualities.

Our *cordite* consists of nitro-glycerine dissolving di-nitro cellulose by the acid of a volatile solvent and a mineral jelly or oil. This compound is semi-fluid, and being passed like macaroni through round holes in a metal plate it forms strings or cords of varying size according to the diameter of the holes. Hence the name, cordite.

Many experiments in search of more powerful explosives resulted in an almost universal adoption of picric acid as the base. This acid is itself produced by the action of nitric acid upon carbolic acid, and each nation has its own fashion of preparing it for artillery.

The French began with *mélinite* in 1885, this being a mixture of picric acid and gun-cotton.

The composition of *lyddite* (named from its place of manufacture, Lydd, in Kent) is a jealously-guarded British secret. This substance was first used in 5-inch howitzers during the last Soudan campaign, playing a part in the bombardment of Omdurman. The effect of the 50-lb. lyddite shells upon the South African kopjes is described as astounding. When the yellow cloud had cleared away trees were seen uprooted, rocks pulverised, the very face of the earth had changed.

Several attempts have been made to utilise dynamite for shells, some of the guns employing compressed air as their motive power. The United States some years ago went to great expense in setting up for this purpose heavy pneumatic plant, which was afterwards disposed of as too cumbrous. Dudley's "Aërial Torpedo" gun discharged a 13-lb. shell containing explosive gelatine, gun-cotton, and fulminate of mercury by igniting the small cordite charge in a parallel tube, through a vent in which the partially cooled gases acted on the projectile in the barrel. This was rotated in the air by inclined blades on a tailpiece, as the barrel could not be rifled for fear of the heat set up by friction. Some guns actuated on much the same principle are said to have been used with effect in the Hispano-American war. Mr. Hudson Maxim with his explosive "maximite", claims to throw half a ton of dynamite about a mile, and a one-ton shell to half that distance.

But even these inventors may some day be outstripped by another, who undertakes to hurl a projectile weighing two tons from an iron tube coiled with copper wire down which an electric current is passed; thus doing away entirely with the need of a firing-charge.

IN THE GUN FACTORY.

Let us pay a visit to one of our gun factories and get some idea of the multiform activities necessary to the turning out complete of a single piece of ordnance or a complicated machine-gun. We enter the enormous workshop, glazed as to roof and sides, full of the varied buzz and whirr and clank of the machinery. Up and down the long bays stand row upon row of lathes, turning, milling, polishing, boring, rifling—all moving automatically, and with a precision which leaves nothing to be desired. The silent attendants seem to have nothing in their own hands, they simply watch that the cutting does not go too far, and with a touch of the guiding handles regulate the pace or occasionally insert a fresh tool. The bits used in these processes are self-cleaning, so the machinery is never clogged; and on the ground lie little heaps of brass chips cut away by the minute milling tools; or in other places it is bestrewn with shavings of brass and steel which great chisels peel off as easily as a carpenter shaves a deal board.

Here an enormous steel ingot, forged solid, heated again and again in a huge furnace and beaten by steam-hammers, or pressed by hydraulic power between each heating till it is brought to the desired size and shape, is having its centre bored through by a special drill which takes out a solid core. This operation is termed "trepanning," and is applied to guns not exceeding eight inches; those of larger calibre being rough-bored on a lathe, and mandrils placed in them during the subsequent forgings. The tremendous heat generated during the boring processes —we may recall how Benjamin Thompson made water boil by the experimental boring of a cannon— is kept down by streams of soapy water continually pumped through and over the metal. We notice this flow of lubricating fluid in all directions, from oil dropping slowly on to the small brass-milling machines to this fountain-play of water which makes a pleasant undertone amidst the jangle of the machines. But these machines are less noisy than we anticipated; in their actual working they emit scarcely the slightest sound. What strikes us more than the supreme exactness with which each does its portion of the work, is the great deliberateness of its proceeding. All the hurry and bustle is above us, caused by the driving-bands from the engine, which keeps the whole machinery of the shed in motion. Suddenly, with harsh creakings, a great overhead crane comes jarring along the bay, drops a chain, grips up a gun-barrel, and, handling this mass of many tons' weight as easily as we should lift a walking-stick, swings it off to undergo another process of manufacture.

We pass on to the next lathe where a still larger forging is being turned externally, supported on specially devised running gear, many different cutters acting upon it at the same time, so that it is gradually assuming the tapering, banded appearance familiar to us in the completed state.

We turn, fairly bewildered, from one stage of manufacture to another. Here is a gun whose bore is being "chambered" to the size necessary for containing the firing charge. Further along we examine a more finished weapon in process of preparation to receive the breech-plug and other fittings. Still another we notice which has been "fine-bored" to a beautifully smooth surface but is being improved yet more by "lapping" with lead and emery powder.

In the next shed a marvellous machine is rifling the interior of a barrel with a dexterity absolutely uncanny, for the tool which does the rifling has to be rotated in order to give the proper "twist" at the same moment as it is advancing lengthwise down the bore. The grooves are not made simultaneously but as a rule one at a time, the distance between them being kept by measurements on a prepared disc.

Now we have reached the apparatus for the wire-wound guns, a principle representing the *ne plus ultra* of strength and durability hitherto evolved The rough-bored gun is placed upon a lathe which revolves slowly, drawing on to it from a reel mounted at one side a continuous layer of steel ribbon about a quarter of an inch wide. On a 12-inch gun there is wound some 117 miles of this wire! fourteen layers of it at the muzzle end and seventy-five at the breech end. Heavy weights regulate the tension of the wire, which varies for each layer, the outermost being at the lowest tension, which will resist a pressure of over 100 tons to the square inch.

We next enter the division in which the gun cradles and mounts are prepared, where we see some of the heaviest work carried out by electric dynamos, the workman sitting on a raised platform to keep careful watch over his business.

Passing through this with interested but cursory inspection of the cone mountings for quick-firing naval guns, some ingenious elevating and training gear and a field carriage whose hydraulic buffers merit closer examination, we come to the shell department where all kinds of projectiles are manufactured. Shrapnel in its various forms, armour-piercing shells, forged steel or cast-iron, and small brass cartridges for the machine-guns may be found here; and the beautifully delicate workmanship of the fuse arrangements attracts our admiration. But we may not linger; the plant for the machine-guns themselves claim our attention.

Owing to the complexity and minute mechanism of these weapons almost a hundred different machines are needed, some of the milling machines taking a large selection of cutters upon one spindle. Indeed, in many parts of the works one notices the men changing their tools for others of different size or application. Some of the boring machines work two barrels at the same time, others can drill three barrels or polish a couple simultaneously. But there are hundreds of minute operations which need to be done separately, down to the boring of screw holes and cutting the groove on a screw-head. Many labourers are employed upon the lock alone. And every portion is gauged correctly to the most infinitesimal fraction, being turned out by the thousand, that every separate item may be interchangeable among weapons of the same make.

Look at the barrel which came grey and dull from its first turning now as it is dealt with changing into bright silver. Here it is adjusted upon the hydraulic rifling machine which will prepare it to carry the small-arm bullet (.303 inch). That one of larger calibre is rifled to fire a small shell. Further on, the barrels and their jackets are being fitted together and the different parts assembled and screwed up. We have not time to follow the perfect implement to its mounting, nor to do more than glance at those howitzers and the breech mechanism of the 6-inch quick-firers near which our guide indicates piles of flat cases to keep the de Bange obturators from warping while out of use. For the afternoon is waning and the foundry still unvisited.

To reach it we pass through the smith's shop and pause awhile to watch a supply of spanners being roughly stamped by an immense machine out of metal plates and having their edges tidied off before they can be further perfected. A steam-hammer is busily engaged in driving mandrils of increasing size through the centre of a red-hot forging. The heat from the forges is tremendous, and though it is tempered by a spray of falling water we are glad to escape into the next shed.

Here we find skilled workmen carefully preparing moulds by taking in sand the exact impression of a wooden dummy. Fortunately we arrive just as a series of casts deeply sunk in the ground are about to be made. Two brawny labourers bear forward an enormous iron crucible, red-hot from the furnace, filled with seething liquid—manganese bronze, we are told—which, when an iron bar is dipped into it, throws up tongues of beautiful greenish-golden flame. The smith stirs and clears off the scum as coolly as a cook skims her broth! Now it is ready, the crucible is again lifted and its contents poured into a large funnel from which it flows into the moulds beneath and fills them to the level of the floor. At each one a helper armed with an iron bar takes his stand and stirs again to work up all dross and air-bubbles to the surface before the metal sets—a scene worthy of a painter's brush.

And so we leave them.

DIRIGIBLE TORPEDOES.

THE history of warlike inventions is the history of a continual see-saw between the discovery of a new means of defence and the discovery of a fresh means of attack. At one time a shield is devised to repel a javelin; at another a machine to hurl the javelin with increased violence against the shield; then the shield is reinforced by complete coats of mail, and so on. The ball of invention has rolled steadily on into our own times, gathering size as it rolls, and bringing more and more startling revolutions in the art of war. To-day it is a battle between the forces of nature, controllable by man in the shape of "high explosives," and the resisting power of metals tempered to extreme toughness.

At present it looks as if, on the sea at least, the attack were stronger than the defence. Our warships may be cased in the hardest metal several inches thick until they become floating forts, almost impregnable to the heaviest shells. They may be provided with terrible engines able to give blow for blow, and be manned with the stoutest hearts in the world. And yet, were a sea-fight in progress, a blow, crushing and resistless, might at any time come upon the vessel from a quarter whence, even though suspected, its coming might escape notice—below the waterline.

It is not possible to cover the under-water part of a ship with armour because of the enormous weight which it would add, and the protective netting with which ships can shield themselves is not a certain protection.

This destructive weapon is an object of awe not so much from what it has done as from what it can do. The instances of a torpedo shivering a vessel in actual warfare are but few. Yet its moral effect must be immense. Even though it may miss its mark, the very fact of its possible presence will, especially at night-time, tend to keep the commanding minds of a fleet very much on the stretch, and to destroy their efficiency. A torpedo knows no half measures. It is either entirely successful or utterly useless. Its construction entails great expense, but inasmuch as it can, if directed aright, send a million of the enemy's money and a regiment of men to the bottom, the discharge of a torpedo is, after all, but the setting of a sprat to catch a whale.

The aim of inventors has been to endow the dirigible torpedo, fit for use in the open sea, with such qualities that when once launched on its murderous course it can pursue its course in the required direction without external help. The difficulties to be overcome in arriving at a serviceable weapon have been very great owing to the complexity of the problem. A torpedo cannot be fired through water like a cannon shell through air. Water, though yielding, is incompressible, and offers to a moving body a resistance increasing with the speed of that body. Therefore the torpedo must contain its own motive power and its own steering apparatus, and be in effect a miniature submarine vessel complete in itself. To be out of sight and danger it must travel beneath the surface and yet not sink to the bottom; to be effective it must possess great speed, a considerable sphere of action, and be able to counteract any chance currents it may meet on its way.

Among purely automobile torpedoes the Whitehead is easily first. After thirty years it still holds the lead for open sea work. It is a very marvel of ingenious adaptation of means to an end, and as it has fulfilled most successfully the conditions set forth above for an effective projectile it will be interesting to examine in some detail this most valuable weapon.

In 1873 one Captain Lupuis of the Austrian navy experimented with a small fireship which he directed along the surface of the sea by means of ropes and guiding lines. This fireship was to be loaded with explosives which should ignite immediately on coming into collision with the vessel aimed at. The Austrian Government declared his scheme unworkable in its crude form, and the Captain looked about for some one to help him throw what he felt to be a sound idea into a practical shape. He found the man he wanted in Mr. Whitehead, who was at that time manager of an engineering establishment at Fiume. Mr. Whitehead fell in enthusiastically with his proposition, at once discarded the complicated system of guiding ropes, and set to work to solve the problem on his own lines. At the end of two years, during which he worked in secret, aided only by a trusted mechanic and a boy, his son, he constructed the first torpedo of the type that bears his name. It was made of steel, was fourteen inches in diameter, weighed 300 lbs., and carried eighteen pounds of dynamite as explosive charge. But its powers were limited. It could attain a rate of but six knots an hour under favourable conditions, and then for a short distance only. Its conduct was uncertain. Sometimes it would run along the surface, at others make plunges for the bottom. However, the British Government, recognising the importance of Mr. Whitehead's work, encouraged him to perfect his instrument, and paid him a large sum for the patent rights. Pattern succeeded pattern, until comparative perfection was reached.

Described briefly, the Whitehead torpedo is cigar-shaped, blunt-nosed and tapering gradually towards the tail, so following the lines of a fish. Its length is twelve times its diameter, which varies in different patterns from fourteen to twenty-one inches. At the fore end is the striker, and at the tail are a couple of three-bladed screws working on one shaft in opposite directions, to economise power and obviate any tendency of the torpedo to travel in a curve; and two sets of rudders, the one horizontal, the other vertical. A torpedo can move at fifty miles an hour, and has a range of 6000 yards.

The torpedo is divided into five compartments by watertight steel bulkheads. At the front is the *explosive head*, containing wet gun-cotton, or some other explosive. The "war head," as it is called, is detachable, and for practice purposes its place is taken by a dummy-head filled with wood to make the balance correct.

Next comes the *air chamber*, filled with highly-compressed air to drive the engines; after it the *balance chamber*, containing the apparatus for keeping the torpedo at its proper depth; then the *engine-room;* and, last of all, the *buoyancy chamber*, which is air-tight and prevents the torpedo from sinking at the end of its run.

To examine the compartments in order:—

In the very front of the torpedo is the pistol and primer-charge for igniting the gun-cotton. Especial care has been taken over this part of the mechanism, to prevent the torpedo being as dangerous to friends as to foes. The pistol consists of a steel plug sliding in a metal tube, at the back end of which is the fulminating charge. Until the plug is driven right in against this charge there can be no explosion. Three precautions are taken against this happening prematurely. In the first place, there is on the forward end of the plug a thread cut, up which a screw-fan travels as soon as it strikes the water. Until the torpedo has run forty-five feet the fan has not reached the end of its travel, and the plug consequently cannot be driven home. Even when the plug is quite free only a heavy blow will drive it in, as a little copper pin has to be sheared through by the impact. And before the screw can unwind at all, a safety-pin must be withdrawn at the moment of firing. So that a torpedo is harmless until it has passed outside the zone of danger to the discharging vessel.

The detonating charge is a small quantity of fulminate of mercury, and the primer-charge consists of several small discs of dry gun-cotton contained in a copper cylinder, the front end of which is connected with the striker-tube of the pistol. The fulminate, on receiving a blow, expands 2500 times, giving a violent shock to the gun-cotton discs, which in turn explode and impart a shock to the main charge, 200 lbs. of gun-cotton.

The *air chamber* is made of the finest compressed steel, or of phosphor-bronze, a third of an inch thick. When ready for action this chamber has to bear a pressure of 1350 lbs. to the square inch. So severe is the compression that in the largest-sized torpedoes the air in this chamber weighs no less than 63 lbs. The air is forced in by very powerful pumps of a special design. Aft of this chamber is that containing the stop-valve and steering-gear. The stop-valve is a species of air-tap sealing the air chamber until the torpedo is to be discharged. The valve is so arranged that it is impossible to insert the torpedo into the firing-tube before the valve has been opened, and so brought the air chamber into communication with the starting-valve, which does not admit air to the engines till after the projectile has left the tube.

The *steering apparatus* is undoubtedly the most ingenious of the many clever contrivances packed into a Whitehead torpedo. Its function is to keep the torpedo on an even keel at a depth determined before the discharge. This is effected by means of two agencies, a swinging weight, and a valve which is driven in by water pressure as the torpedo sinks. When the torpedo points head downwards the weight swings forward, and by means of connecting levers brings the horizontal rudders up. As the torpedo rises the weight becomes vertical and the rudder horizontal. This device only insures that the torpedo shall travel horizontally. The valve makes it keep its proper depth by working in conjunction with the pendulum. The principle, which is too complicated for full description, is, put briefly, a tendency of the valve to correct the pendulum whenever the latter swings too far. Lest the pendulum should be violently shaken by the discharge there is a special controlling gear which keeps the rudders fixed until the torpedo has proceeded a certain distance, when the steering mechanism is released. The steering-gear does not work directly on the rudder. Mr. Whitehead found in his earlier experiments that the pull exerted by the weight and valve was not sufficient to move the rudders against the pressure of the screws. He therefore introduced a beautiful little auxiliary engine, called the servo-motor, which is to the torpedo what the steam steering-gear is to a ship. The servo-motor, situated in the *engine-room*, is only four inches long, but the power it exerts by means of compressed air is so great that a pressure of half an ounce exerted by the steering-gear produces a pull of 160 lbs. on the rudders.

The steering apparatus is powerfully assisted by a gyroscope, a small but heavy flywheel which is revolved at a speed of several thousand revolutions per minute, and which therefore tends to keep itself in the same position, just as a spinning-top tends to keep upright. Thus it keeps the torpedo pointing in the original direction, and prevents it swerving away from its proper path.

The engines which drive the torpedo by compressed air are small but very powerful. They draw their supply of air from the air-chamber, and as this becomes exhausted chemicals come into action which heat up what remains, and so help to maintain the pressure. This arrangement has greatly added to the range of the weapon.

Whitehead torpedoes are fired from tubes above or below the waterline. Deck tubes have the advantage of being more easily aimed, but when loaded they are a source of danger, as any stray bullet or shell from an enemy's ship might explode the torpedo with dire results. There is therefore an increasing preference for submerged tubes. An ingenious device is used for aiming the torpedo, which makes allowances for the speed of the ship from which it is fired, the speed of the ship aimed at, and the speed of the torpedo-itself. When the moment for firing arrives, the officer in charge presses an electric button, which sets in motion an electric magnet fixed to the side of the tube. The magnet releases a heavy ball which falls and turns the "firing rod." Compressed air or a powder discharge is brought to bear on the rear end of the torpedo, which, if submerged, darts out from the vessel's side along a guiding bar, from which it is released at both ends simultaneously, thus avoiding the great deflection towards the stern which would occur were a broadside torpedo not held at the nose till the tail is clear. This guiding apparatus enables a torpedo to leave the side of a vessel travelling at high speed almost at right angles to the vessel's path.

It will be easily understood that a Whitehead torpedo is a costly projectile, and that its value—£500 or more—makes the authorities very careful of its welfare. During practice with "blank" torpedoes a "Holmes light" is attached. This light is a canister full of calcium phosphide to which water penetrates through numerous holes, causing gas to be thrown off and rise to the surface, where, on meeting with the oxygen of the air, it bursts into flame and gives off dense volumes of heavy smoke, disclosing the position of the torpedo by night or day.

At Portsmouth are storehouses containing upwards of a thousand torpedoes. Every torpedo is at intervals taken to pieces, examined, tested, and put together again after full particulars have been taken down on paper. Each steel "baby" is kept bright and clean, coated with a thin layer of oil, lest a single spot of rust should mar its beauty. An interesting passage from Lieutenant G. E. Armstrong's book on "Torpedoes and Torpedo Vessels" will illustrate the scrupulous exactness observed in all things relating to the torpedo depôts: "As an example of the care with which the stores are kept it may be mentioned that a particular tiny pattern of brass screw which forms part of the torpedo's mechanism and which is valued at about twopence-halfpenny per gross, is never allowed to be a single number wrong. On one occasion, when the stocktaking took place, it was found that instead of 5000 little screws being accounted for by the man who was told off to count them, there were only 4997. Several foolscap letters were written and exchanged over these three small screws, though their value was not more than a small fraction of a farthing."

The classic instance of the effectiveness of this type of torpedo is the battle of the Yalu, fought between the Japanese and Chinese fleets in 1894. The Japanese had been pounding their adversaries for hours with their big guns without producing decisive results. So they determined upon a torpedo attack, which was delivered early in the morning under cover of darkness, and resulted in the destruction of a cruiser, the *Ting Yuen.* The next night a second incursion of the Japanese destroyers wrecked another cruiser, the *Lai Yuen,* which sank within five minutes of being struck; sank the *Wei Yuen,* an old wooden vessel used as a training-school; and blew a large steam launch out of the water on to an adjacent wharf. These hits "below the belt" were too much for the Chinese, who soon afterwards surrendered to their more scientific and better equipped foes.

If a general war broke out to-day most of the nations would probably pin their faith on the Whitehead for use in the open sea, although for harbour defence the Brennan or its American rival, the Sims-Edison, might be used by some. The two last named are both controlled from the shore by means of wires, so that they can hunt down their prey, as it were, but the very presence of the wires makes them unsuitable for use in a fleet action.

The Brennan, although it is not now used by the British Navy, is a most interesting invention. Its inventor was a Melbourne watchmaker. Being a comparatively poor man, he applied to the Colonial Government for grants to aid him in the manufacture and development of his torpedo, and he was supplied with sufficient money to perfect it. In 1881 he was requested by the British Admiralty to bring his invention to England, where it was tried and found to be so efficient for harbour and creek defence that the British Government were advised by their experts to pay him a large sum of money for his patents, and for his services in connection with the torpedo. Thus, unlike the majority of inventors, he became a rich man.

The Brennan torpedo derives its motive power from a very powerful engine on shore, capable of developing 100 horse-power, with which it is connected by stout piano wires. One end of these wires is wound on two reels inside the torpedo, each working a screw; the other end is attached to two winding drums driven at high velocity by the engine on shore. As the drums wind in the wire the reels in the torpedo revolve; consequently, the harder the torpedo is pulled back the faster it moves forward, liked a trained trotting mare. The steering of the torpedo is effected by alterations in the relative speeds of the drums, and consequently of the screws. The drums run loose on the engine axle, and are thrown in or out of gear by means of a friction-brake, so that their speed can be regulated without altering the pace of the engines. Any increase in the speed of one drum causes a corresponding decrease in the speed of the other. The torpedo can be steered easily to right or left within an arc of forty degrees on each side of straight ahead; but when once launched it cannot be retrieved except by means of a boat. Its path is marked by a Holmes light, described above. It has a 200-lb. guncotton charge, and is fitted with an apparatus for maintaining a proper depth very similar to that used in the Whitehead torpedo.

The Sims-Edison torpedo differs from the Brennan in its greater obedience to orders and in its motive power being electrically transmitted through a single connecting cable. It is over thirty feet in length and two feet in diameter. Attached to the torpedo proper by rods is a large copper float, furnished with balls to show the operator the path of the torpedo. The torpedo itself is in four parts: the explosive head; the magazine of electric cables, which is paid out as the torpedo travels; the motor room; and the compartment containing the steering-gear. The projectile has a high speed and long range—over four thousand yards. It can twist and turn in any direction, and, if need be, be called to heel. Like the Brennan, it has the disadvantage of a long trailing wire, which could easily become entangled; and it might be put out of action by any damage inflicted on its float by the enemy's guns. But it is likely to prove a very effective harbour-guard if brought to the test.

In passing to the Orling-Armstrong torpedo we enter the latest phase of torpedo construction. Seeing the disadvantages arising from wires, electricians have sought a means of controlling torpedoes without any tangible connection. Wireless telegraphy showed that such a means was not beyond the bounds of possibility. Mr. Axel Orling, a Swede, working in concert with Mr. J. T. Armstrong, has proved that a torpedo can be steered by waves of energy transmitted through the ether, much as wireless messages are sent.

It is said that after being dropped into the water these weird objects can be made to wander about in any direction and at any desired level, to go straight, or to turn to the right or the left, all in perfect obedience to the will of the man who is handling the controlling instrument ashore.

In order that this man might be able to follow the movements of his charge, and also as a receiver for the wireless impulses, a mast of some sort has to project upon the torpedo's back, and originally a mast with a small flag was used. Since, however, this was so liable to be destroyed by the enemy's fire some better arrangement had to be thought of, and the inventor, Mr. Armstrong, has said that it came to him in a dream. It certainly was an inspiration however it came, for his idea was to make the machine suck in water, and then blow it upwards in a jet, just as a whale does when it comes to the surface to breathe. This water-mast answers ideally, so it is said, for receiving the wireless control, and it is quite evident that the enemy might blaze away at it all day long without inflicting the slightest harm upon it.

Another curious feature of this torpedo is the way in which it is designed to avoid the torpedo nets which are intended to keep it at "arm's length" away from a big ship. On striking such netting it for a moment reverses its engines; then it goes ahead again, but steers itself downwards, after a while rising again inside the netting. If all goes as arranged, it should come up at just the right angle to strike a deadly blow.

But wonderful though all these torpedoes are as inventions they are all more or less failures, even the Whiteheads. In the Russo-Japanese war many ships were struck by torpedoes, but they did comparatively little damage. True they did some, in a few instances disabling ships, but they did not destroy them. Mines, on the other hand, in several instances, blew great battleships to absolute destruction in a few minutes. It was a mine which sent Admiral Makharoff to his death, and it was by similar means that the Japanese battleship *Hatsuse* was sunk. Mines, however, carry much larger charges of explosive than a torpedo can do, which readily accounts for the difference. Torpedoes ought, then, to be made to carry more, but that is just the difficulty. A mine is practically all explosive, but a torpedo must from the very nature of things be largely machinery, and she must not be too heavy to float, nor must she be too clumsy to be easily handled and controlled.

After the great naval war in the Far East, when the comparative failure of the torpedo became apparent, the Italian Government thought they would try some experiments to see for themselves what a torpedo could do. So they got an old battleship of obsolete pattern which they had no further use for, and made it the object of a torpedo attack. They did not send the torpedo at it in the ordinary way, however, for in that particular case they wanted to give the weapon every advantage, so as to prove the very best it could do under ideally favourable circumstances. They fixed it therefore to the side of the old ship as she lay at anchor at the spot which they deemed the most vulnerable of all. Then it was fired by electricity from a safe distance, and the fine old ship heeled over and sank.

For a long while she remained at the bottom (and may be there still), but divers have been down to her and report that a huge rent of an area of 50 square metres was torn in her side.

This has to a certain extent revived the credit of the torpedo after the suspicions cast upon it by its feeble behaviour in actual warfare; but it must be borne in mind that the chances of a torpedo sent from a distance hitting a ship just in the best way and at the right spot must be at any rate hundreds to one against, if not thousands, and in that may lie the explanation of the difference between the result of the experiment and the actual performance under war conditions.

Anyway, the torpedo has yet to justify itself in battle, and if anyone can improve upon it so as to make it of greater explosive strength there is a fine chance for him.

SUBMARINE BOATS.

THE introduction of torpedoes for use against an enemy's ships below the waterline has led by natural stages to the evolution of a vessel which may approach unsuspected close enough to the object of attack to discharge its missile effectively. Before the searchlight was adopted a night surprise gave due concealment to small craft; but now that the gloom of midnight can be in an instant flooded with the brilliance of day a more subtle mode of attack becomes necessary.

Hence the genesis of the submarine or submersible boat, so constructed as to disappear beneath the sea at a safe distance from the doomed ship, and when its torpedo has been sped to retrace its invisible course until outside the radius of destruction.

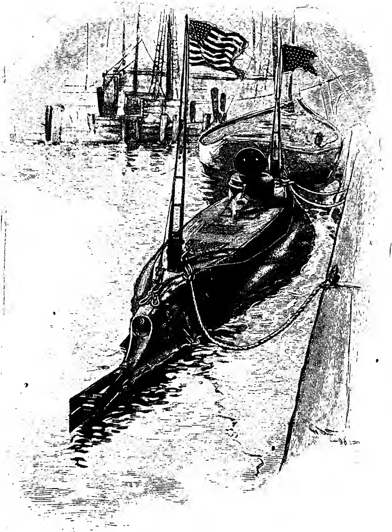
To this end many so-called submarine boats have been invented and experimented with during recent years. The idea is an ancient one revived, as indeed are the large proportion of our boasted modern discoveries.

Aristotle describes a vessel of this kind (a diving-bell rather than a boat, however), used in the siege of Tyre more than two thousand years ago; and also refers to the divers being provided with an air-tube, "like the trunk of an elephant," by means of which they drew a fresh supply of air from above the surface—a contrivance adopted in more than one of our modern submarines. Alexander the Great is said to have employed divers in warfare; Pliny speaks of an ingenious diving apparatus, and Bacon refers to air-tubes used by divers. We even find traces of weapons of offence being employed. Calluvius is credited with the invention of a submarine gun for projecting Greek fire.

The Bishop of Upsala in the sixteenth century gives a somewhat elaborate description of certain leather skiffs or boats used to scuttle ships by attacking them from beneath, two of which he claims to have personally examined. In 1629 we read that the Barbary corsairs fixed submarine torpedoes to the enemy's keel by means of divers.

As early as 1579 an English gunner named William Bourne patented a submarine boat of his own invention fitted with leather joints, so contrived as to be made smaller or larger by the action of screws, ballasted with water, and having an air-pipe as mast. The Campbell-Ash submarine tried in 1885 was on much the same principle.

Cornelius van Drebbel, an ingenious Dutchman who settled in England before 1600, produced certain submersible vessels and obtained for them the patronage of two kings. He claims to have discovered a means of re-oxygenating the foul air and so enabling his craft to remain a long time below water; whether



The "Holland" Submarine Boat.

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appreciated engineers of the early years of the nineteenth century. His *Nautilus*, built in the French dockyards, was in many respects the pattern for our own modern submarines. The cigar-shaped copper hull, supported by iron ribs, was twenty-four feet four inches long, with a greatest diameter of seven feet. Propulsion came from a wheel, rotated by a hand winch, in the centre of the stern; forward was a small conning-tower, and the boat was steered by a rudder. There was a detachable keel below; and fitted into groves on the top were a collapsible mast and sail for use on the surface of the water. An anchor was also carried externally. In spite of the imperfect materials at his disposal Fulton had much success. At Brest he took a crew of three men twenty-five feet down, and on another day blew up an old hulk. In the Seine two men went down for twenty minutes and steered back to their starting-point under water. He also put in air at high pressure and remained submerged for hours. But France, England, and his own country in turn rejected his invention; and, completely discouraged, he bent his energies to designing boat engines instead.

In 1821 Captain Johnson, also an American, made a submersible vessel 100 feet long, designed to fetch Napoleon from St. Helena, travelling for the most part upon the surface. This expedition never came off.

Two later inventions, by Castera and Payerne, in 1827 and 1846 respectively, were intended for more peaceful objects. Being furnished with diving-chambers, the occupants could retrieve things from the bottom of the sea; Castera providing his boat with an air-tube to the surface.

Bauer, another inventor, lived for some years in England under the patronage of Prince Albert, who supplied him with funds for his experiments. With Brunel's help he built a vessel which was indiscreetly modified by the naval authorities, and finally sank and drowned its crew. Going then to Russia he constructed sundry submarines for the navy; but was in the end thrown over, and, like Fulton, had to turn himself to other employment.

The fact is that up to this period the cry for a practical submarine to use in warfare had not yet arisen, or these inventions would have met with a far different reception. Within the last half century all has changed. During that time the submarine has developed by leaps and bounds.

Starting in the time of the American Civil War, we find that both sides tried their inventive powers in the hope of bringing out a serviceable submarine. The Southerners were specially enterprising in this, and produced a number of little vessels to which they gave the name of Davids, because of their expected success against the Goliath-like ships of the enemy. One of these got so far as to attack the Northern ironclad *New Ironsides*, which was taking part in the blockade of Charleston. It succeeded in discharging a torpedo, which was carried on the end of a long pole, but the resultant damage was negligible.

This partial success encouraged the building of another and larger David, but for a long time she was pursued by nothing but the worst of ill-fortune. Crew after crew were drowned in her, but at last she brought off a triumphant success.

Creeping out one night from the port of Charleston she made her way unnoticed to the farther, seaward side of the blockading squadron, where she marked down for her prey the fine new ship *Housatonic* belonging to the Federals. The officers of the Northern fleet had been warned and so were on the watch, but they were so sure that the attack would come from the landward side that the little David was able to draw quite near without being seen. When discovered she was so close that the larger vessel's guns were not able to hit her; they could not be pointed low enough. So she carefully and at leisure sought out the best spot, discharged her torpedo, and the great ship was so seriously holed that she quickly sank.

So runs the story of the only successful operation ever accomplished in warfare by a submarine. Many have drowned their crews in time of peace, but on this occasion only has a blow been inflicted on an enemy. And in this case it must be admitted the little craft was not acting as a submarine but as a surface torpedo boat. Her previous ill-fortune made her crew so nervous that they would not allow her to be shut down so as to sink below the surface. Because of this they were swamped and drowned in the moment of success, whereas had they been securely covered in they might possibly have escaped. Another instance of the fact that fortune favours the brave.

In the following years inventors were very busy, and to describe all the queer vessels which were drawn upon paper, and some of which actually entered the water, would take more space than we can afford. We can only pick out those which naturally lead up to the submarines which have proved successful.

Most of these emanate from France and America. Two boats, for example, built by a Frenchman, M. Goubet, in 1885 and 1889 respectively, had many valuable points which were later on embodied in those built by the French Government.

Then we come to the *Gymnote*, built for the French Navy, laid down in 1888. It was cigar-shaped, 29 feet long by 6 feet diameter, with a displacement of thirty tons. The motive power was also electricity stored in accumulators for use during submersion, and the speed expected—but not realised—was to have been ten knots.

Five years later this type was improved upon in the *Gustave Zédé*, the largest submarine of its time. This boat, built of phosphor-bronze, with a single screw, measured 131 feet in length and had a displacement of 266 tons; she could contain a crew of nine officers and men, carried three torpedoes—though with one torpedo tube instead of two—had a lightly armoured conning-tower, and it is said gave a surface speed of thirteen knots, and to have made eight knots when submerged. At a trial of her powers made in the presence of M. Lockroy, Minister of Marine, she affixed an unloaded torpedo to the battleship *Magenta* and got away unobserved. The whole performance of the boat on that occasion was declared to be most successful. But its cost proved excessive considering the small radius of action obtainable, and a smaller vessel of the same type, the ***Morse*** (118 by 9 feet), became the favourite.

In 1896 a competition was held and won by the submersible ***Narval*** of M. Laubeuf, a craft shaped much like the ordinary torpedo-boat. On the surface or awash the *Narval* works by means of a Brulé engine burning oil fuel to heat its boilers; but when submerged for attack with funnel shut down is driven by electric accumulators. She displaces 100 odd tons and is provided with four Dzewiecki torpedo tubes. Her radius of action, steaming awash, is calculated at some 250 miles, or seventy miles when proceeding under water at five knots an hour. This is the parent of another class of boats designed for offensive tactics, while the ***Morse*** type is adapted chiefly for coast and harbour defence. The French Navy now includes a great number of submarine craft, though several of these are only projected at present, and none have yet been put to the practical tests of actual warfare—the torpedoes used in experimenting being, of course, blank.

Meanwhile in America experiments had also been proceeding since 1887, when Mr. Holland of New York produced the vessel that bears his name. This, considerably modified, has now been adopted as model by our Navy Department, which has built up a large fleet on very similar lines. Though it is not easy to get any definite particulars concerning French submarines Americans are less reticent, and we have graphic accounts of the *Holland* and her offspring from those who have visited her.

These vessels, though cigar-shaped like most others, in some respects resemble the *Narval*, being intended for long runs on the surface, when they burn oil in a four-cylinder gasolene engine of 160 horse-power. Under water they are propelled by an electric waterproof motor of seventy horse-power, and proceed at a pace of seven knots per hour. There is a superstructure for deck, with a funnel for the engine and a small conning-tower protected by 4-inch armour. The armament carried comprises five 18-inch Whitehead torpedoes, 11 feet 8 inches long. One hundred and twenty tons is the displacement, including tank capacity for 850 gallons of gasolene; the full length is 63 feet 4 inches, with a beam of 11 feet 9 inches.

The original Holland boat is thus described by an adventurous correspondent who took a trip in her[1]: "The *Holland* is fifty-three feet long, and in its widest part it is 10½ feet in diameter. It has a displacement of seventy-four tons, and what is called a reserve buoyancy of 2½ tons which tends to make it come to the surface.

"The frames of the boat are exact circles of steel. They are set a little more than a foot apart. They diminish gradually in diameter from the centre of the boat to the bow and stern. On the top of the boat a flat superstructure is built to afford a walking platform, and under this are spaces for exhaust pipes and for the external outfit of the boat, such as ropes and a small anchor. The steel plates which cover the frame are from one-half to three-eighths of an inch in thickness.

"From what may be called the centre of the boat a turret extends upwards through the superstructure for about eighteen inches. It is two feet in diameter, and is the only means of entrance to the boat. It is the place from which the boat is operated. At the stern is an ordinary three-bladed propeller and an ordinary rudder, and in addition there are two horizontal rudders—"diving-rudders" they are called—which look like the feet of a duck spread out behind as it swims along the water.

"From the bow two-thirds of the way to the stern there is a flooring, beneath which are the storage batteries, the tank for the gasolene, and the tanks which are filled with water for submerging; in the

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[1] *Pearson's Magazine.*

last one-third of the boat the flooring drops away, and the space is occupied by the propelling machinery.

"There are about a dozen openings in the boat, the chief being three Kingston valves, by means of which the submerging tanks are filled or emptied. Others admit water to pressure gauges, which regulate or show the depth of the vessel under water. There are twelve deadlights in the top and sides of the craft. To remain under water the boat must be kept in motion, unless an anchor is used.

"It can be steered to the surface by the diving rudders, or sent flying to the top through emptying the storage tanks. If it strikes bottom, or gets stuck in the mud, it can blow itself loose by means of its compressed air. It cannot be sunk unless pierced above the flooring. It has a speed capacity of from eight to ten knots either on the surface or under water.

"It can go 1500 miles on the surface without renewing its supply of gasolene. It can go fully forty knots under water without coming to the surface, and there is enough compressed air in the tanks to supply a crew with fresh air for thirty hours, if the air is not used for any other purpose, such as emptying the submerging tanks. It can dive to a depth of twenty feet in eight seconds.

"The interior is simply packed with machinery. As you climb down the turret you are confronted with it at once. There is a diminutive compass which must be avoided carefully by the feet. A pressure gauge is directly in front of the operator's eye as he stands in position. There are speaking-tubes to various parts of the boat, and a signal-bell to the engine-room.

"As the operator's hands hang by his sides, he touches a wheel on the port side, by turning which he steers the little vessel, and one on the starboard side, by turning which he controls the diving machinery. After the top is clamped down the operator can look out through tiny plate-glass windows, about one inch wide and three inches long, which encircle the turret.

"So long as the boat is running on the surface these are valuable, giving a complete view of the surroundings if the water is smooth. After the boat goes beneath the surface, these windows are useless; it is impossible to see through the water. Steering must be done by compass; until recently considered an impossible task in a submarine boat. A tiny electric light in the turret shows the operator the direction in which he is going, and reveals the markings on the depth gauges. If the boat should pass under an object, such as a ship, a perceptible shadow would be noticed through the deadlights, but that is all. The ability to see fishes swimming about in the water is a pleasant fiction.

"The only clear space in the body of the boat is directly in front of the bench on which the man in the turret is standing. It is where the eighteen-inch torpedo-tube, and the eight and five-eighths inch aërial gun are loaded.

"Along the sides of this open space are six compressed-air tanks, containing thirty cubic feet of air at a pressure of 2000 lbs. to a square inch. Near by is a smaller tank, containing three cubic feet of air at a fifty pounds pressure. A still smaller tank contains two cubic feet of air at a ten pounds pressure. These smaller tanks supply the compressed air which, with the smokeless powder, is used in discharging the projectiles from the boat.

"Directly behind the turret, up against the roof on the port side, is the little engine by which the vessel is steered; it is worked by compressed air. Fastened to the roof on the starboard side is the diving-engine, with discs that look as large as dinner-plates stood on end. These discs are diaphragms on which the water-pressure exerts an influence, counteracting certain springs which are set to keep the diving rudders at a given pitch, and thus insuring an immersion of an exact depth during a run.

"At one side is a cubic steel box—the air compressor; and directly in the centre of this part of the boat is a long pendulum, just as there is in the ordinary torpedo, which, by swinging backwards and forwards as the boat dives and rises, checks a tendency to go too far down, or to come up at too sharp an angle. On the floor are the levers which, when raised and moved in certain directions, fill or empty the submerging tanks. On every hand are valves and wheels and pipes in such apparent confusion as to turn a layman's head.

"There are also pumps in the boat, a ventilating apparatus, and a sounding contrivance, by means of which the channel is picked out when running under water. This sounding contrivance consists of a heavy weight attached to a piano wire passing from a reel out through a stuffing-box in the bottom. There are also valves which release fresh air to the crew, although in ordinary runs of from one-half to one hour this is not necessary, the fresh air received from the various exhausts in the boat being sufficient to supply all necessities in that length of time."

Another submersible of somewhat different design is the production of the Swedish inventor, Mr. Nordenfelt. This boat is 9½ metres in length, and has a displacement of sixty tons. Like the *Goubet* it sinks only in a horizontal position, while the *Holland* plunges downward at a slight angle. On the surface a steam-engine of 100 horse-power propels it, and when the funnel is closed down and the vessel submerges itself, the screws are still driven by superheated steam from the large reservoir of water boiling at high pressure which maintains a constant supply, three circulation pumps keeping this in touch with the boiler. The plunge is accomplished by means of two protected screws, and when they cease to move the reserve buoyancy of the boat brings it back to the surface. It is steered by a rudder which a pendulum regulates. The most modern of these boats is of

English manufacture, built at Barrow, and tried in Southampton Water.

The vessels hitherto described should be termed submersible rather than submarine, as they are designed to usually proceed on the surface, and submerge themselves only for action when in sight of the enemy.

American ingenuity has produced an absolutely unique craft to which the name submarine may with real appropriateness be applied, for, sinking in water 100 feet deep, it can remain below and run upon three wheels along the bottom of the sea. This is the *Argonaut*, invented by Mr. Simon Lake of Baltimore, and its main portion consists of a steel framework of cylindrical form which is surmounted by a flat, hollow steel deck. During submersion the deck is filled with water and thus saved from being crushed by outside pressure as well as helping to sink the craft.

When moving on the surface it has the appearance of an ordinary ship, with its two light masts, a small conning-tower on which is the steering-wheel, bowsprit, ventilators, a derrick, suction-pump, and two anchors. A gasolene engine of special design is used for both surface and submerged cruising under ordinary circumstances, but in time of war storage batteries are available. An electric dynamo supplies light to the whole interior, including a 4000 candle-power searchlight in the extreme bow which illuminates the pathway while under water.

On the boat being stopped and the order given to submerge, the crew first throw out sounding lines to make sure of the depth. They then close down external openings, and retreat into the boat through the conning-tower, within which the helmsman takes his stand, continuing to steer as easily as when outside. The valves which fill the deck and submersion tanks are opened, and the *Argonaut* drops gently to the floor of the ocean. The two apparent masts are in reality 3-inch iron pipes which rise thirty feet or more above the deck, and so long as no greater depth is attained, they supply the occupants with fresh air and let exhausted gases escape, but close automatically when the water reaches their top.

Once upon the bottom of the sea this versatile submarine begins its journey as a tricycle. It is furnished with a driving-wheel on either side, each of which is 6½ feet in diameter and weighs 5000 lbs.; and is guided by a third wheel weighing 2000 lbs. journalled in the rudder. On a hard bottom or against a strong tide the wheels are most effective owing to their weight, but in passing through soft sand or mud the screw propeller pushes the boat along, the driving-wheels running "loose." In this way she can travel through even waist-deep mud, the screw working more strongly than on the surface, because it has such a weight of water to help it, and she moves more easily uphill.

In construction the *Argonaut* is shaped something like a huge cigar, her strong steel frames, spaced twenty inches apart, being clad with steel plates ⅝-inch thick double riveted over them. Great strength is necessary to resist the pressure of superincumbent water, which at a depth of 100 feet amounts to 44 lbs. per square inch.

Originally she was built 36 feet long, but was subsequently lengthened by some 20 odd feet, and has 9 feet beam. She weighs fifty-seven tons when submerged. A false section of keel, 4000 lbs. in weight, can on emergency be instantly released from inside; and two downhaul weights, each of 1000 lbs., are used as an extra precaution for safety when sinking in deep water.

The interior is divided into various compartments, the living quarters consisting of the cabin, galley, operating chamber and engine-room. There are also a division containing stores and telephone, the intermediate, and the divers' room. The "operating" room' contains the levers, handwheels, and other mechanism by which the boat's movements are governed. A water gauge shows her exact depth below the surface; a dial on either side indicates any inclination from the horizontal. Certain levers open the valves which admit water to the ballast-tanks in the hold; another releases the false keel; there is a cyclometer to register the wheel travelling, and other gauges mark the pressure of steam, speed of engines, &c.

A compass in the conning-tower enables the navigator to steer a true course whether above or below the surface. This conning-tower, only six feet high, rises above the centre of the living quarters, and is of steel with small windows in the upper part. Encircling it to about three-quarters of its height is a reservoir for gasolene, which feeds into a smaller tank within the boat for consumption. The compressed air is stored in two Mannesmann steel reservoirs which have been tested to a pressure of 4000 lbs. per square inch. This renews the air-supply for the crew when the *Argonaut* is long below, and also enables the diving operations to be carried on.

The maximum speed at which the *Argonaut* travels submerged is five knots an hour, and when she has arrived at her destination—say a sunken coal steam —the working party pass into the "intermediate chamber, whose air-tight doors are then closed. A current of compressed air is then turned on until th air is equal in pressure to that in the divers' roon The doors of this close over indiarubber to be air an water-tight; one communicates with the "intermed ate," the other is a trap which opens downwards int the sea. Through three windows in the prow those remaining in the room can watch operations outside within a radius varying according to the clearness of the water. The divers assume their suits, to the helmets of which a telephone is attached, so arranged that they are able to talk to each other as well as to those in the boat. They are also provided with electric lamps, and a brilliant flood of light streams upon them from the bows of the vessel. The derrick can be used with ease under water, and the powerful suction-pump will "retrieve" coal from a submerged vessel into a barge above at the rate of sixty tons per hour.

It will thus be seen how valuable a boat of this kind may be for salvage operations, as well as for surveying the bottom of harbours, river mouths, sea coasts, and so on. In war time it can lay or examine submarine mines for harbour defence, or, if employed offensively, can enter the enemy's harbour with no chance of detection, and there destroy his mines or blow up his ships with perfect impunity.

To return the *Argonaut* to the surface it is only necessary to force compressed air into the space below the deck and the four tanks in the hold. Her buoyancy being thus gradually restored she rises slowly and steadily till she is again afloat upon the water, and steams for land.

We have now glanced briefly at some of the most interesting attempts out of a great number to produce a practical submarine vessel in bygone days, and have inquired more closely into the construction of several of more modern design. It must have struck the patriotic reader, too, that Great Britain figures very poorly in these accounts, and probably he is tempted to make the conventional exclamation, "Behind, as usual."

Let him cheer up, however, for of recent years we Britishers have developed a very peculiar but valuable characteristic. Not only in submarines, but in engineering matters generally, we have got into the way of letting other people do the drudgery, throw away money on fruitless experiments, and so on, and when they have at last hit upon something good we very soon make them share it with us. Napoleon said we were a nation of shopkeepers, and while what I have just described may not be heroic it is certainly good shopkeeping.

So we looked on while the submarine by painful experience was being evolved, but as soon as it seemed practical we bought the best that was to be got. Our Admiralty chose that of Mr. Holland, and they purchased his designs. At the great Vickers shipbuilding yard at Barrow-in-Furness these designs were translated into an actual submarine, and in 1901 there was launched what was known as Holland No. 1. Others followed in quick succession, each one being a further improvement. Soon there came the A class of 180 tons, 100 feet long, and capable of 11 knots on the surface and 7 knots below. The B class which followed are 300 tons, 150 feet long, with speeds of 13 and 9 knots. Slightly larger still are the C's, whose speeds are 14 and 10 knots. The D's and E's are larger still, approaching 1000 tons.

British submarines now carry guns, and are fitted for wireless telegraphy.

Just what these are like inside no one outside the service knows, for they are the most closely guarded of secrets. They are believed, however, to be improved editions of the Holland boat described earlier.

Just a word about the sinking of these boats. It is done by a combination of two forces. First of all water is admitted into suitable tanks until the boat is nearly but not quite as heavy as the water. Consequently she only just floats. Then she goes ahead, and by means of her horizontal rudders steers herself downwards. This is very important, for it means that she always has a reserve of buoyancy, and should her machinery stop for any reason, up she comes to the surface automatically.

But suppose she is damaged in some way and, shipping some water, becomes too heavy. Even then the men have, in the case of the newer boats, a chance of escape. For the interior is subdivided by steel curtains, as we might call them, depending from the roof, so that some air is sure to be entrapped in the upper part of her. In these air-pockets are stored a simple form of diving dress, one for each member of the crew. To them, therefore, the men repair in time of danger, and putting on these helmets can float up to the surface and so to safety.

The helmet is combined with a jacket, loose-fitting so as to be easily put on, and thin so that it can be folded up small for storage. Inside this helmet and jacket are chemicals which will keep the enclosed air pure for an hour or so, and in addition to that the man can so inflate his dress by blowing into a part of it, which is double, as to convert it into a life-belt. With this to support him he can open the window of his helmet when he reaches the surface, and float in safety, if need be, for *more* than the hour which his chemical aids allow him.

Then another interesting feature is the periscope, by which the commander of a submarine, himself hidden, sees what is going on above. It is a combination of the camera obscura and the telescope. A reflector or prism at the top of a tube projecting above the water throws downwards a picture of what is before it. Guided by lenses, the rays of light pass eventually into the man's eye in the interior of the boat. Only a narrow and restricted view is thus presented to him, but it enables him to grope his way about. As several sad calamities have shown, however, it only permits him to see one way at a time, and several submarines have been lost through being struck by another ship which has approached unobserved while the periscope was no doubt pointed another way.

An interesting question is how these underwater war vessels are to be fought. If above water they would be an easy prey to the speedy destroyer, for they cannot go very fast, not even the best of them, while destroyers are the fastest vessels afloat. But when they dive it is difficult to get at them. Even if they can be seen they are hard to hit. Two destroyers towing between them a huge fishing-net has been suggested, and certainly a submarine so caught would be in a very awkward predicament, for a very little pull from outside would turn her over and over, so delicately is she poised. A spar torpedo is another idea. This is a box of explosives on the end of a pole, with which perhaps a destroyer might charge a submarine, like a mediæval knight with his lance, exploding the torpedo close to the submerged boat. It takes a little time for a submarine to dive, and a destroyer so armed and fairly near to start with might be able to come up with the smaller craft before she had got out of sight. A powerful explosion acting through the incompressible water might be enough to crush the submarine, even if it occurred some distance away.

In the daytime submarines can be seen in the water if looked at vertically. The refraction of light by the surface of the water prevents them from being seen if looked at in a slanting direction, and since the higher one is the more surface one can look down upon in a practically vertical direction, it follows that the higher an observer is placed the more likely he is to be able to see a submarine down below. Hence it is proposed to use captive balloons sent up from the deck of a larger ship or aeroplanes for hunting for submarines.

Indeed the problem of the future is now not so much how to make an effective submarine, but how to fight against them.

ANIMATED PICTURES.

HAS it ever occurred to the reader to ask himself why rain appears to fall in streaks though it arrives at earth in drops? Or why the glowing end of a charred stick produces fiery lines if waved about in the darkness? Common sense tells us the drop and the burning point cannot *be* in two places at one and the same time. And yet apparently we are able to see both in many positions simultaneously.

This seeming paradox is due to "persistence of vision," a phenomenon that has attracted the notice of scientific men for many centuries. Persistence may be briefly explained thus:—

The eye is extremely sensitive to light, and will, as is proved by the visibility of the electric spark, lasting for less than the millionth part of a second, *receive* impressions with marvellous rapidity.

But it cannot get rid of these impressions at the same speed. The duration of a visual impression has been calculated as one-tenth to one-twenty-first of a second. The electric spark, therefore, appears to last much longer than it really does.

Hence it is obvious that if a series of impressions follow one another more rapidly than the eye can free itself of them, the impressions will overlap, and one of four results will follow.

(*a*) ***Apparently uninterrupted presence*** of an image if the same image be repeatedly represented.

(*b*) ***Confusion***, if the images be all different and disconnected.

(*c*) ***Combination***, if the images of two or a very few objects be presented in regular rotation.

(*d*) ***Motion***, if the objects be similar in all but one part, which occupies a slightly different portion in each presentation.

In connection with (*c*) an interesting story is told of Sir J. Herschel by Charles Babbage :—[1]

"One day Herschel, sitting with me after dinner, amusing himself by spinning a pear upon the table, suddenly asked whether I could show him the two sides of a shilling at the same moment. I took out of my pocket a shilling, and holding it up before the looking-glass, pointed out my method. 'No,' said my friend, 'that won't do;' then spinning my shilling upon the table, he pointed out his method of seeing both sides at once. The next day I mentioned the anecdote to the late Dr. Fitton, who a few days after brought me a beautiful illustration of the principle. It consisted of a round disc of card suspended between two pieces of sewing silk. These threads being held between the finger and thumb of each hand, were

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[1] Quoted from Mr. Henry V. Hopwood's "Living Pictures," to which book the author is indebted for much of his information in this chapter.

then made to turn quickly, when the disc of card, of course, revolved also. Upon one side of this disc of card was painted a bird, upon the other side an empty bird-cage. On turning the thread rapidly the bird appeared to have got inside the cage. We soon made numerous applications, as a rat on one side and a trap on the other, &c. It was shown to Captain Kater, Dr. Wollaston, and many of our friends, and was, after the lapse of a short time, forgotten. Some months after, during dinner at the Royal Society Club, Sir Joseph Banks being in the chair, I heard Mr. Barrow, then secretary to the Admiralty, talking very loudly about a wonderful invention of Dr. Paris, the object of which I could not quite understand. It was called the Thaumatrope, and was said to be sold at the Royal Institution, in Albemarle Street. Suspecting that it had some connection with our unnamed toy I went next morning and purchased for seven shillings and sixpence a thaumatrope, which I afterwards sent down to Slough to the late Lady Herschel. It was precisely the thing which her son and Dr. Fitton had contributed to invent, which amused all their friends for a time, and had then been forgotten."

The *thaumatrope*, then, did nothing more than illustrate the power of the eye to weld together a couple of alternating impressions. The toys to which we shall next pass represent the same principle working in a different direction towards the production of the living picture.

Now, when we see a man running (to take an instance) we see the *same* body and the same legs continuously, but in different positions, which merge insensibly the one into the other. No method of reproducing that impression of motion is possible if only *one* drawing, diagram, or photograph be employed.

A man represented with as many legs as a centipede would not give us any impression of running or movement; and a blur showing the positions taken successively by his legs would be equally futile. Therefore we are driven back to a *series* of pictures, slightly different from one another; and in order that the pictures may not be blurred a screen must be interposed before the eye while the change from picture to picture is made. The shorter the period of change, and the greater the number of pictures presented to illustrate a single motion, the more realistic is the effect. These are the general principles which have to be observed in all mechanism for the production of an illusory effect of motion. The persistence of vision has led to the invention of many optical toys, the names of which, in common with the names of most apparatus connected with the living picture, are remarkable for their length. Of these toys we will select three for special notice.

In 1833 Plateau of Ghent invented the *phenakistoscope*, "the thing that gives one a false impression of reality"—to interpret this formidable word. The phenakistoscope is a disc of card or metal round the edge of which are drawn a succession of pictures showing a man or animal in progressive positions. Between every two pictures a narrow slit is cut. The disc is mounted on an axle and revolved before a mirror, so that a person looking through the slits see one picture after another reflected in the mirror.

The *zoetrope*, or Wheel of Life, which appeared first in 1860, is a modification of the same idea. In this instrument the pictures are arranged on the inner side of a hollow cylinder revolving on a vertical axis, its sides being perforated with slits above the pictures. As the slit in both cases caused distortion M. Reynaud, a Frenchman, produced in 1877 the *praxinoscope*, which differed from the zoetrope in that the pictures were not seen directly through slits, but were reflected by mirrors set half-way between the pictures and the axis of the cylinder, a mirror for every picture. Only at the moment when the mirror is at right angles to the line of sight would the picture be visible. M. Reynaud also devised a special lantern for projecting praxinoscope pictures on to a screen.

These and other somewhat similar contrivances, though ingenious, had very distinct limitations. They depended for their success upon the inventiveness and accuracy of the artist, who was confined in his choice of subject; and could, owing to the construction of the apparatus, only represent a small series of actions, indefinitely repeated by the machine. And as a complete action had to be crowded into a few pictures, the changes of position were necessarily abrupt.

To make the living picture a success two things were needed; some method of securing a very rapid series of many pictures, and a machine for reproducing the series, whatever its length. The method was found in photography, with the advance of which the living picture's progress is so closely related, that it will be worth while to notice briefly the various improvements of photographic processes. The old-fashioned Daguerreotype process, discovered in 1839, required an exposure of half-an-hour. The introduction of wet collodion reduced this tax on a sitter's patience to ten seconds. In 1878 the dry plate process had still further shortened the exposure to one second; and since that date the silver-salt emulsions used in photography have had their sensitiveness to light so much increased, that clear pictures can now be made in one-thousandth of a second, a period minute enough to arrest the most rapid movements of animals.

By 1878, therefore, instantaneous photography was ready to aid the living picture. Previously to that year series of photographs had been taken from posed models, without however extending the choice of subjects to any great extent. But between 1870 and 1880 two men, Marey and Muybridge, began work with the camera on the movements of horses. Marey endeavoured to produce a series of pictures round the edge of one plate with a single lens and repeated exposures.[1] Muybridge, on the other hand, used a series of cameras. He erected a long white background parallel to which were stationed the cameras at equal distances. The shutters of the cameras were connected to threads laid across the interval between the background and the cameras in such a manner that a horse driven along the track snapped them at regular intervals, and brought about successive exposures. Muybridge's method was carried on by Anschütz, a German, who in 1899 brought out his electrical Tachyscope, or "quick-seer." Having secured his negatives he printed off transparent positives on glass, and arranged these last round the circumference of a large disc rotating in front of a screen, having in it a hole the size of the transparencies. As each picture came opposite the hole a Geissler tube was momentarily lit up behind it by electrical contact, giving a fleeting view of one phase of a horse's motion.

The introduction of the ribbon film in or about 1888 opened much greater possibilities to the living picture than would ever have existed had the glass plate been retained. It was now comparatively easy to take a long series of pictures; and accordingly we find Messrs. Friese-Greene and Evans exhibiting in 1890 a camera capable of securing three hundred exposures in half a minute, or ten per second.

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[1] A very interesting article in the May, 1902, issue of *Pearson's Magazine* deals with the latest work of Professor Marey in the field of the photographic representation of the movements of men, birds, and quadrupeds.

The next apparatus to be specially mentioned is Edison's Kinetoscope, which he first exhibited in England in 1894. As early as 1887 Mr. Edison had tried to produce animated pictures in a manner analogous to the making of a sound-record on a phonograph (see p. 56). He wrapped round a cylinder a sheet of sensitized celluloid which was covered, after numerous exposures, by a spiral line of tiny negatives. The positives made from these were illuminated in turn by flashes of electric light. This method was, however, entirely abandoned in the perfected kinetoscope, an instrument for viewing pictures the size of a postage stamp, carried on a continuously moving celluloid film between the eye of the observer and a small electric lamp. The pictures passed the point of inspection at the rate of forty-six per second (a rate hitherto never approached), and as each picture was properly centred a slit in a rapidly revolving shutter made it visible for a very small fraction of a second. Holes punched at regular intervals along each side of the film engaged with studs on a wheel, and insured a regular motion of the pictures. This principle of a perforated film has been used by nearly all subsequent manufacturers of animatographs.

To secure forty-six negatives per second Edison invented a special exposure device. Each negative would have but one-forty-sixth of a second to itself, and that must include the time during which the fresh surface of film was being brought into position before the lens. He therefore introduced an intermittent gearing, which jerked the film forwards forty-six times per second, but allowed it to remain stationary for nine-tenths of the period allotted to each picture. During the time of movement the lens was covered by the shutter. This principle of exposure has also been largely adopted by other inventors. By its means weak negatives are avoided, while pictures projected on to a screen gain greatly in brilliancy and steadiness.

The capabilities of a long flexible film-band having been shown by Edison, he was not long without imitators. Phantoscopes, Bioscopes, Photoscopes, and many other instruments followed in quick succession. In 1895 Messrs. Lumière scored a great success with their Cinematograph, which they exhibited at Marseilles and Paris; throwing the living picture as we now know it on to a screen for a large company to see. This camera-lantern opens the era of commercial animated-photography. The number of patents taken out since 1895 in connection with living-picture machines is sufficient proof that inventors have either found in this particular branch of photography a peculiar fascination, or have anticipated from it a substantial profit.

The modern kinematograph machine is much like an ordinary magic-lantern, with a little apparatus in the front of it.

The film has holes along either edge to enable two wheels with projecting teeth to catch hold of it and pass it through the machine. It is thus passed by a series of jerks through the lantern much as the ordinary slide is passed, but of course much quicker. In front of the nozzle of the lantern is a revolving disc with a number of holes in it. This is so geared to the machinery which passes the film along, that just at the moment of "stationariness" between two jerks a hole passes in front of the nozzle and so allows the light to pass to the screen, carrying the picture, so to speak, with it. Thus the picture is flashed upon the screen while the film is at rest; while it is moving the solid part of the disc is in front of the nozzle, and the light is for the moment cut off. This rapid series of pictures, as already explained, the eye naturally weaves together into one apparently living picture.

PICTURES BY WIRE.

In an earlier chapter we have told of a wonderful apparatus by which writing and sketches can be wired in facsimile from one place to another. There are other equally marvellous inventions by which photographs can be sent by wire, and even "by wireless," very quickly and with wonderful clearness.

We will commence with the scheme of Messrs. Ayrton and Perry, two names well known in the electrical world.

Imagine a hollow glass cylinder with a photograph on its outside. This photograph must be either on the glass itself or on some transparent substance like celluloid, for it is necessary to send a tiny beam of light through it. Inside the cylinder there will be an electric light so arranged with a lens that all the light is concentrated into a finely pointed pencil, piercing the picture at one small point. Then let the cylinder be revolved, and at the same time gradually travelled along. By that means the light pencil will in turn pierce every part of the photograph, and the amount of the light which passes through the picture and emerges at the outside will at any moment be in proportion to the density of the picture at some point. It will be, in fact, just as if the picture were cut into a long fine spiral, and the amount of light which issues from the apparatus at any moment will denote the lightness or darkness of the spiral at the point which the beam is piercing at that moment.

Already we have noticed the peculiar virtue of the metal selenium, whereby it allows more or less electric current to pass, according to the amount of light which falls upon it. When, therefore, the pencil of light is piercing a thin part of the picture, and is therefore falling strongly upon a neighbouring selenium cell, a strong current will flow, whereas on a dark part intervening between the light and the cell the current will be feeble. So the variations of light and shade in the picture are converted into variations in the strength of an electric current.

That current can pass along a wire, and if it can be converted back at the other end the picture will be reproduced. Let us then pass in imagination to the other end and see how that is done.

Here we must picture to ourselves another cylinder exactly the same size as the first, and revolving and travelling at precisely the same speed. It is enclosed in a dark chamber and covered with a sheet of photographic paper. A lamp is so arranged that the movement of a tiny shutter will permit more or less of a pencil of light to fall upon one spot on the paper. When the shutter is closed no light will fall; when partly open a little will pass; when fully open still more; and so on. If then the movements of the shutter be controlled by the current arriving from the other instrument, the light passed by the shutter will vary as did the original pencil of light after passing through the picture. Thus a spiral line will be drawn, so to speak, by the pencil of light upon the cylinder of photographic paper, just like the spiral into which we have imagined the picture to be cut up. This spiral line, varying as it will do in density, will build up the picture, and so it will have been communicated over the wire.

Another method invented by Amstutz consists in the use of a "carbon" photograph with its hills and dales, projections and depressions. Most enthusiastic photographers have at some time or another had a try at this interesting process, and will know that the picture consists of a film of gelatine which is thick in the dark parts and exceedingly thin in the high lights. Indeed, the picture is entirely made up of variations in the thickness of the film. So a print of this description being placed upon a revolving cylinder, with a stylus trailing upon it and moving at the same time slowly from one end to the other as the needle does in a phonograph, the stylus will rise and fall as the part passed over is dark or light. This movement can be made to control an electric current, which arriving at the other end makes a similar stylus cut more or less deeply into a cylinder of soft metal. This metal can then be used as a block for printing the picture.

Professor Korn, in his telautograph, utilises the same principles as Messrs. Ayrton and Perry.

But probably the most successful of all is the telectrograph invented by Mr. Thorne-Baker. It is used largely by the London illustrated paper, the *Daily Mirror*, which frequently publishes photographs which by its aid have been sent over the wires. From the north of England, even from Paris, pictures are sent.

The sending apparatus has for its main feature a specially made half-tone block. These blocks, by which the modern printer produces such excellent illustrations, are obtained by photographing the picture to be reproduced through a screen consisting of a sheet of glass ruled across with a vast number of fine lines. The width and distance apart of the lines varies according to whether fine detail is wanted in the print or only broad effects. Anyone who cares to examine the illustrations in this volume through a magnifying glass will perceive the lines running across, one set at right angles to the other. They cut up the picture into a vast number of tiny points equally numerous all over the picture (except for the perfectly white part), but varying in size. Where the points are fine the effect of light is produced; where they are large the deepest shadows appear. The variations in the size of the points, indeed, make up the picture, and they are so small that looked at from a little distance we do not see them, but only the effects which they produce. The photograph is taken upon a special plate of the old wet type, the advantage of which is that it can be developed in a very short time. A print is taken on a copper plate covered with photographic film, and then the picture is etched into the copper with acid. Mounted upon a wooden support that copper plate forms the block from which the illustration is printed, as if it were a piece of type.

Now suppose that instead of a screen with lines and cross lines we had one in which the lines ran one way only. The resulting picture would then not consist of dots of varying size, but of parallel lines of varying width. The light parts of the picture would be where the lines are fine, the dark ones where they are broad. It is blocks of this special type which are made for the telectrograph, and they are made on tin-foil instead of copper.

Now let us imagine that we have got one of these tin-foil blocks of a picture which we want to communicate by wire. We first of all roll the foil round a metal drum. Next we set the drum rotating, and as it turns a delicate little arm trails over it. We are careful to put on the foil in such a manner that the lines run lengthwise of the drum, and so as it turns the arm traverses *across* the lines. They are, of course, projecting lines upon the surface of the foil, with depressions between them, and so the arm, being of metal and suitably connected, receives electric current so long as it is in contact with a line, but no current when over a depression. Thus, in passing over a fine line but a momentary current is sent into the arm, while if it be a thick line the current persists for so much the longer.

The arm all the time is slowly creeping along in the direction of the axis of the drum, just as the sounding apparatus of a phonograph does. Consequently, at each succeeding revolution it passes round a different part of the drum from that which it passed over previously.

The current is fed to the drum, and passing thence to the arm speeds away through the main wire or "line" to the distant station. Thus the picture is, as it were, translated into a vast number of tiny currents of electricity, and it only remains to translate them back correctly at the other end.

We are already familiar with the idea of a current recording its presence by making a mark on chemically prepared paper. The same method is used here. At the receiving end there is a drum exactly similar to that at the sending end, and moving at the same speed. It is covered with the prepared paper, and as it turns a slight arm or stylus trails over its surface, just as does the corresponding part of the sending machine.

So as the sending stylus passes over a line the receiving stylus pours out the current and makes a mark—a short line, as long as the sending line is wide. Both drums move in unison : each stylus moves sideways at precisely the same speed as the other : and so the tiny currents are translated back at the receiving end into a picture very similar to that on the foil in the transmitting instrument.

The picture thus built up of innumerable tiny lines, drawn as we might say with electricity for ink, can then be photographed again, and a block made off it for printing from, just as can be done with any other picture.

To understand the wonderful accuracy of this machine it may be said that the tiny electrical impulses which are sent through the wires number about 175 per second, and as each one must fall into its right place it follows that the two drums must not vary in speed by more than the tiniest fraction of a second. For instance, if they revolve nominally twice per second their times of rotation should not differ by more than a thousandth of a second.

This accuracy is attained by an electric current sent from the transmitting end, starting them both at the same moment, and after that the transmitter sending periodical correcting currents, so that if the receiving drum is getting ahead it is slowed down, and *vice versâ*.

Only an electrician can appreciate the excellence of this apparatus, for there are many subtle electrical adjustments to be made before those 175 currents per second can be induced to report themselves intelligently at the receiving end. It is just as if they got demoralised on the way, and it was only by incessant experimenting, innumerable failures, and great expense that ways were at last found of disciplining them so as to compel them to do their duty truthfully.

Any reader who has puzzled through the subject of wireless telegraphy, referred to earlier, will see that it is quite possible to apply the wireless method to this system of picture telegraphy.

THE GREAT PARIS TELESCOPE

A TELESCOPE so powerful that it brings the moon apparently to within thirty-five miles of the earth; so long that many a cricketer could not throw a ball from one end of it to the other; so heavy that it would by itself make a respectable load for a goods train; so expensive that astronomically-inclined millionaires might well hesitate to order a similar one for their private use.

Such is the huge Paris telescope that in 1900 delighted thousands of visitors in the French Exposition, where, among the many wonderful sights to be seen on all sides, it probably attracted more notice than any other exhibit. This triumph of scientific engineering and dogged perseverance in the face of great difficulties owes its being to a suggestion made in 1894 to a group of French astronomers by M. Deloncle. He proposed to bring astronomy to the front at the coming Exposition, and to effect this by building a refracting telescope that in size and power should completely eclipse all existing instruments and add a new chapter to the "story of the heavens."

To the mind unversed in astronomy the telescope appeals by the magnitude of its dimensions, in the same way as do the Forth Bridge, the Eiffel Tower, the Big Wheel, the statue of Liberty near New York harbour, the Pyramids, and most human-made "biggest on records."

At the time of M. Deloncle's proposal the largest refracting telescope was the Yerkes' at William's Bay, Wisconsin, with an object-glass forty inches in diameter; and next to it the 36-inch Lick instrument on Mount Hamilton, California, built by Messrs. Alvan Clark of Cambridgeport, Massachusetts. Among reflecting telescopes the prior place is still held by Lord Rosse's, set up on the lawn of Birr Castle half a century ago. Its speculum, or mirror, weighing three tons, lies at the lower end of a tube six feet across and sixty feet long. This huge reflector, being mounted in meridian, moves only in a vertical direction. A refracting telescope is one of the ordinary pocket type, having an object-lens at one end and an eyepiece at the other. A reflector, on the other hand, has no object-lens, its place being taken by a mirror that gathers the rays entering the tube and reflects them back into the eyepiece, which is situated nearer the mouth end of the tube than the mirror itself.

Each system has its peculiar disadvantages. In reflectors the image is more or less distorted by "spherical aberration." In refractors the image is approximately perfect in shape, but liable to "chromatic aberration," a phenomenon especially noticeable in cheap telescopes and field-glasses, which often show objects fringed with some of the colours of the spectrum. This defect arises from the different refrangibility of different light rays. Thus, violet rays come to a focus at a shorter distance from the lens than red rays, and when one set is in focus to the eye the other must be out of focus. In carefully-made and expensive instruments compound lenses are used, which by the employment of different kinds of glass bring all the colours to practically the same focus, and so do away with chromatic aberration.

To reduce colour troubles to a *minimum* M. Deloncle proposed that the object-lens should have a focal distance of about two hundred feet, since a long focus is more easily corrected than a short one, and a diameter of over fifty-nine inches. The need for so huge a lens arises out of the optical principles of a refractor. The rays from an object—a star, for instance—strike the object-glass at the near end, and are bent by it into a converging beam, till they all meet at the focus. Behind the focus they again separate, and are caught by the eyepiece, which reduces them to a parallel beam small enough to enter the pupil. We thus see that though the unaided eye gathers only the few rays that fall directly from the object on to the pupil, when helped by the telescope it receives the concentrated rays falling on the whole area of the object-glass; and it would be sensible of a greatly increased brightness had not this light to be redistributed over the image, which is the object magnified by the eyepiece. Assuming the aperture of the pupil to be one-tenth of an inch, and the object to be magnified a hundred times, the object-lens should have a hundred times the diameter of the pupil to render the image as bright as the object itself. If the lens be five instead of ten inches across, a great loss of light results, as in the high powers of a microscope, and the image loses in distinctness what it gains in size.

As M. Deloncle meant his telescope to beat all records in respect of magnification, he had no choice but to make a lens that should give proportionate illumination, and itself be of unprecedented size.

At first M. Deloncle met with considerable opposition and ridicule. Such a scheme as his was declared to be beyond accomplishment. But in spite of many prophecies of ultimate failure he set to work, entrusting the construction of the various portions of his colossal telescope to well-tried experts. To M. Gautier was given the task of making all the mechanical parts of the apparatus; to M. Mantois the casting of the giant lenses; to M. Despret the casting of the huge mirror, to which reference will be made immediately.

The first difficulty to be encountered arose from the sheer size of the instrument. It was evidently impossible to mount such a leviathan in the ordinary way. A tube, 180 feet long, could not be made rigid enough to move about and yet permit careful observation of the stars. Even supposing that it were satisfactorily mounted on an "equatorial foot" like smaller glasses, how could it be protected from wind and weather? To cover it, a mighty dome, two hundred feet or more in diameter, would be required; a dome exceeding by over seventy feet the cupola of St. Peter's, Rome; and this dome must revolve easily on its base at a pace of about fifty feet an hour, so that the telescope might follow the motion of the heavenly bodies.

The constructors therefore decided to abandon any idea of making a telescope that could be moved about and pointed in any desired direction. The alternative course open to them was to fix the telescope itself rigidly in position, and to bring the stars within its field by means of a mirror mounted on a massive iron frame—the two together technically called a siderostat. The mirror and its support would be driven by clockwork at the proper sidereal rate. The siderostat principle had been employed as early as the eighteenth century, and perfected in recent years by Léon Foucault, so that in having recourse to it the builders of the telescope were not committing themselves to any untried device.

In days when the handling of masses of iron, and the erection of huge metal constructions have become matters of everyday engineering life, no peculiar difficulty presented itself in connection with the metal-work of the telescope. The greatest possible care was of course observed in every particular. All joints and bearings were adjusted with an extraordinary accuracy; and all the cylindrical moving parts of the siderostat verified till they did not vary from perfect cylindricity by so much as one twenty-five-thousandth of an inch!

The tube of the telescope, 180 feet long, consisted of twenty-four sections, fifty-nine inches in diameter, bolted together and supported on seven massive iron pillars. It weighed twenty-one tons. The siderostat, twenty-seven feet high, and as many in length, weighed forty-five tons. The lower portion, which was fixed firmly on a bed of concrete, had on the top a tank filled with quicksilver, in which the mirror and its frame floated. The quicksilver supported nine-tenths of the weight, the rest being taken by the levers used to move the mirror. Though the total weight of the mirror and frame was thirteen tons, the quicksilver offered so little resistance that a pull of a few pounds sufficed to rotate the entire mass.

The real romance of the construction of this huge telescope centres on the making of the lenses and mirror. First-class lenses for all photographic and optical purposes command a very high price on account of the care and labour that has to be expended on their production; the value of the glass being trifling by comparison. Few, if any, trades require greater mechanical skill than that of lens-making; the larger the lens the greater the difficulties it presents, first in the casting, then in the grinding, last of all in the polishing. The presence of a single air-bubble in the molten glass, the slightest irregularity of surface in the polishing may utterly destroy the value of a lens otherwise worth several thousands of pounds.

The object-glass of the great telescope was cast by M. Mantois, famous as the manufacturer of large lenses. The glass used was boiled and reboiled many times to get rid of all bubbles. Then it was run into a mould and allowed to cool very gradually. A whole month elapsed before the breaking of a mould, when the lens often proved to be cracked on the surface, owing to the exterior having cooled faster than the interior and parted company with it. At last, however, a perfect cast resulted.

M. Despret undertook the even more formidable task of casting the mirror at his works at Jeumont, North France. A special furnace and oven, capable of containing over fifteen tons of molten glass, had to be constructed. The mirror, 6½ feet in diameter and eleven inches thick, absorbed 3¾ tons of liquid glass; and so great was the difficulty of cooling it gradually, that out of the twenty casts eighteen were failures.

The rough lenses and mirror having been ground to approximate correctness in the ordinary way, there arose the question of polishing, which is generally done by one of the most sensitive and perfect instruments existing—the human hand. In this case, owing to the enormous size of the objects to be treated, hand work would not do. The mere hot touch of a workman would raise on the glass a tiny protuberance, which would be worn level with the rest of the surface by the polisher, and on the cooling of the part would leave a depression, only 1-75,000 of an inch deep, perhaps, but sufficient to produce distortion, and require that the lens should be ground down again, and the whole surface polished afresh.

M. Gautier therefore polished by machinery. It proved a very difficult process altogether, on account of frictional heating, the rise of temperature in the polishing room, and the presence of dust. To insure success it was found necessary to warm all the polishing machinery, and to keep it at a fixed temperature.

At the end of almost a year the polishing was finished, after the lenses and mirror had been subjected to the most searching tests, able to detect irregularities not exceeding 1-250,000 of an inch. M. Gautier applied to the mirror M. Foucault's test, which is worth mentioning. A point of light thrown by the mirror is focused through a telescope. The eyepiece is then moved inwards and outwards so as to throw the point out of focus. If the point becomes a luminous circle surrounded by concentric rings, the surface throwing the light point is perfectly plane or smooth. If, however, a pushing-in shows a vertical flattening of the point, and a pulling-out a horizontal flattening, that part is concave; if the reverse happens, convexity is the cause.

For the removal of the mirror from Jeumont to Paris a special train was engaged, and precautions were taken rivalling those by which travelling Royalty is guarded. The train ran at night without stopping, and at a constant pace, so that the vibration of the glass atoms might not vary. On arriving at Paris, the mirror was transferred to a ponderous waggon, and escorted by a body of men to the Exposition buildings. The huge object-lens received equally careful treatment.

The telescope was housed at the Exhibition in a long gallery pointing due north and south, the siderostat at the north end. At the other, the eyepiece, end, a large amphitheatre accommodated the public assembled to watch the projection of stellar or lunar images on to a screen thirty feet high, while a lecturer explained what was visible from time to time. The images of the sun and moon as they appeared at the primary focus in the eyepiece measured from twenty-one to twenty-two inches in diameter, and the screen projections were magnified from these about thirty times superficially.

The eyepiece section consisted of a short tube, of the same breadth as the main tube, resting on four wheels that travelled along rails. Special gearing moved this truck-like construction backwards and forwards to bring a sharp focus into the eyepiece or on to a photographic plate. Focusing was thus easy enough when once the desired object came in view; but the observer being unable to control the siderostat, 250 feet distant, had to telephone directions to an assistant stationed near the mirror whenever he wished to examine an object not in the field of vision.

By the courtesy of the proprietors of the *Strand*

Magazine we are allowed to quote M. Deloncle's own words describing his emotions on his first view through the giant telescope :—

"As is invariably the case, whenever an innovation that sets at nought old-established theories is brought forward, the prophecies of failure were many and loud, and I had more than a suspicion that my success would cause less satisfaction to others than to myself. Better than any one else I myself was cognisant of the unpropitious conditions in which my instrument had to work. The proximity of the river, the dust raised by hundreds of thousands of trampling feet, the trepidation of the soil, the working of the machinery, the changes of temperature, the glare from the thousands of electric lamps in close proximity—each of these circumstances, and many others of a more technical nature, which it would be tedious to enumerate, but which were no less important, would have been more than sufficient to make any astronomer despair of success even in observatories where all the surroundings are chosen with the utmost care.

"In regions pure of calm and serene air large new instruments take months, more often years, to regulate properly.

"In spite of everything, however, I still felt confident. Our calculations had been gone over again and again, and I could see nothing that in my opinion warranted the worst apprehensions of my kind critics.

"It was with ill-restrained impatience that I waited for the first night when the moon should show herself in a suitable position for being observed; but the night arrived in due course.

"Everything was in readiness. The movable portion of the roof of the building had been slid back, and the mirror of the siderostat stood bared to the sky.

"In the dark, square chamber at the other end of the instrument, 200 feet away, into which the eyepiece of the instrument opened, I had taken my station with two or three friends. An attendant at the telephone stood waiting at my elbow to transmit my orders to his colleague in charge of the levers that regulated the siderostat and its mirror.

"The moon had risen now, and her silvery glory shone and sparkled in the mirror.

"'A right declension,' I ordered.

"The telephone bell rang in reply. 'Slowly, still slower; now to the left—enough; again a right declension—slower; stop now—very, very slowly.'

"On the ground-glass before our eyes the moon's image crept up from one corner until it had overspread the glass completely. And there we stood in the centre of Paris, examining the surface of our satellite with all its craters and valleys and bleak desolation.

"I had won the day."

PHOTOGRAPHING THE INVISIBLE.

Most of us are able to recognise when we see them shadowgraphs taken by the aid of the now famous X-rays. They generally represent some part of the structure of men, beasts, birds, or fishes. Very dark patches show the position of the bones, large and small; lighter patches the more solid muscles clinging to the bony framework; and outside these again are shadowy tracts corresponding to the thinnest and most transparent portions of the fleshy envelope.

In an age fruitful as this in scientific marvels, it often takes some considerable time for the public to grasp the full importance of a fresh discovery. But when, in 1896, it was announced that Professor Röntgen of Würzburg had actually taken photographs of the internal organs of still living creatures, and penetrated metal and other opaque substances with a new kind of ray, great interest was manifested throughout the civilised world. On the one hand the "new photography" seemed to upset popular ideas of opacity; on the other it savoured strongly of the black art, and, by its easy excursions through the human body, seemed likely to revolutionise medical and surgical methods. At first many strange ideas about the X-rays got afloat, attributing to them powers which would have surprised even their modest discoverer. It was also thought that the records were made in a camera after the ordinary manner of photography, but as a matter of fact Röntgen used neither lens nor camera, the operation being similar to that of casting a shadow on a wall by means of a lamp. In X-radiography a specially constructed electrically-lit glass tube takes the place of the lamp, and for the wall is substituted a sensitised plate. The object to be radiographed is merely inserted between them, its various parts offering varying resistance to the rays, so that the plate is affected unequally, and after exposure may be developed and printed from in the usual way. Photographs obtained by using X-rays are therefore properly called shadowgraphs or skiagraphs.

The discovery that has made Professor Röntgen famous is, like many great discoveries, based upon the labours of other men in the same field. Geissler, whose vacuum tubes are so well known for their striking colour effects, had already noticed that electric discharges sent through very much rarefied air or gases produced beautiful glows. Sir William Crookes, following the same line of research, and reducing with a Sprengel air-pump the internal pressure of the tubes to $\frac{1}{1000000}$ of an atmosphere, found that a luminous glow streamed from the cathode, or negative pole, in a straight line, heating and rendering phosphorescent anything that it met.

Crookes regarded the glow as composed of "radiant matter," and explained its existence as follows. The airy particles inside the tube, being few in number, are able to move about with far greater freedom than in the tightly packed atmosphere outside the tube. A particle, on reaching the cathode, is repelled violently by it in a straight line, to "bombard" another particle, the walls of the tube, or any object set up in its path, the sudden arrest of motion being converted into light and heat.

By means of special tubes he proved that the "radiant matter" could turn little vanes, and that the flow continued even when the terminals of the shocking-coil were *outside* the glass, thus meeting the contention of Puluj that the radiant matter was nothing more than small particles of platinum torn from the terminals. He also showed that, when intercepted, radiant matter cast a shadow, the intercepting object receiving the energy of the bombardment; but that when the obstruction was removed the hitherto sheltered part of the glass wall of the tube glowed with a brighter phosphorescence than the part which had become "tired" by prolonged bombardment. Experiments further revealed the fact that the shaft of "Cathode rays" could be deflected by a magnet from their course, and that they affected an ordinary photographic plate exposed to them.

In 1894 Lenard, a Hungarian, and pupil of the famous Hertz, fitted a Crookes' tube with a "window" of aluminium in its side replacing a part of the glass, and saw that the course of the rays could be traced through the outside air. From this it was evident that something else than matter must be present in the shaft of energy sent from the negative terminal of the tube, as there was no direct communication between the interior and the exterior of the tube to account for the external phosphorescence. Whatever was the nature of the rays he succeeded in making them penetrate and impress themselves on a sensitised plate enclosed in a metal box.

Then in 1895 came Röntgen's great discovery that the rays from a Crookes' tube, after traversing the *glass*, could pierce opaque matter. He covered the tube with thick cardboard, but found that it would still cast the shadows of books, cards, wood, metals, the human hand, &c., on to a photographic plate even at the distance of some feet. The rays would also pass through the wood, metal, or bones in course of time; but certain bodies, notably metals, offered a much greater resistance than others, such as wood, leather, and paper. Professor Röntgen crowned his efforts by showing that a skeleton could be "shadowgraphed" while its owner was still alive.

Naturally everybody wished to know not only what the rays could do, but what they were. Röntgen, not being able to identify them with any known rays, took refuge in the algebraical symbol of the unknown quantity and dubbed them X-rays. He discovered this much, however, that they were invisible to the eye under ordinary conditions; that they travelled in straight lines only, passing through a prism, water, or other refracting bodies without turning aside from their path; and that a magnet exerted no power over them. This last fact was sufficient of itself to prevent their confusion with the radiant matter "cathode rays" of the tube. Röntgen thought, nevertheless, that they might be the cathode rays transmuted in some manner by their passage through the glass, so as to resemble in their motion sound-waves, *i.e.* moving straight forward and not swaying from side to side in a series of zig-zags. The existence of such ether waves had for some time before been suspected by Lord Kelvin.

Other authorities have other theories. We may mention the view that X represents the ultra-violet rays of the spectrum, caused by vibrations of such extreme rapidity as to be imperceptible to the human eye, just as sounds of extremely high pitch are inaudible to the ear. This theory is to a certain extent upheld by the behaviour of the photographic plate, which is least affected by the colours of the spectrum at the red end and most by those at the violet end. A photographer is able to use red or orange light in his dark room because his plates cannot "see" them, though he can; whereas the reverse would be the case with X-rays. This ultra-violet theory claims for X-rays a rate of ether vibration of trillions of waves per second.

An alternative theory is to relegate the rays to the gap in the scale of ether-waves between heat-waves and light-waves. But this does not explain any more satisfactorily than the other the peculiar phenomenon of non-refraction.

The apparatus employed in X-photography consists of a Crookes' tube of a special type, a powerful shocking or induction coil, a fluorescent screen and photographic plates and appliances for developing, &c., besides a supply of high-pressure electricity derived from the main, a small dynamo or batteries.

A Crookes' tube is four to five inches in diameter, globular in its middle portion, but tapering away towards each end. Through one extremity is led a platinum wire, terminating in a saucer-shaped platinum plate an inch or so across. At the focus of this, the negative terminal, is fixed a platinum plate at an angle to the path of the rays so as to deflect them through the side of the tube. The positive terminal penetrates the glass at one side. The tube contains, as we have seen, a very tiny residue of air. If this were entirely exhausted the action of the tube would cease; so that some tubes are so arranged that when rarefaction becomes too high the passage of an electrical current through small bars of chemicals, whose ends project through the sides of the tube, liberates gas from the bars in sufficient quantity to render the tube active again.

When the Ruhmkorff induction coil is joined to the electric circuit a series of violent discharges of great rapidity occur between the tube terminals, resembling in their power the discharge of a Leyden jar, though for want of a dense atmosphere the brilliant spark has been replaced by a glow and brush-light in the tube. The coil is of large dimensions, capable of passing a spark across an air-gap of ten to twelve inches. It will perhaps increase the reader's respect for X-rays to learn that a coil of proper size contains upwards of thirteen miles of wire; though indeed this quantity is nothing in comparison with the 150 miles wound on the huge inductorium formerly exhibited at the London Polytechnic.

If we were invited to an X-ray demonstration we should find the operator and his apparatus in a darkened room. He turns on the current and the darkness is broken by a velvety glow surrounding the negative terminal, which gradually extends until the whole tube becomes clothed in a green phosphorescence. A sharply-defined line athwart the tube separates the shadowed part behind the receiving plate at the negative focus—now intensely hot—from that on which the reflected rays fall directly.

One of us is now invited to extend a hand close to the tube. The operator then holds on the near side of the hand his fluorescent screen, which is nothing more than a framework supporting a paper smeared on one side with platinocyanide of barium, a chemical that, in common with several others, was discovered by Salvioni of Perugia to be sensitive to the rays and able to make them visible to the human eye. The value of the screen to the X-radiographer is that of the ground-glass plate to the ordinary photographer, as it allows him to see exactly what things are before the sensitised plate is brought into position, and in fact largely obviates the necessity for making a permanent record.

The screen shows clearly and in full detail all the bones of the hand—so clearly that one is almost irresistibly drawn to peep behind to see if a real hand is there. One of us now extends an arm and the screen shows us the *ulna* and the *radius* working round each other, now both visible, now one obscuring the other. On presenting the body to the course of the rays a remarkable shadow is cast on to the screen. The spinal column and the ribs; the action of the heart and lungs are seen quite distinctly. A deep breath causes the movement of a dark mass—the liver. There is no privacy in presence of the rays. The enlarged heart, the diseased lung, the ulcerated liver betrays itself at once. In a second of time the phosphorescent screen reveals what might baulk medical examination for months.

If a photographic slide containing a dry-plate be substituted for the focusing-screen, the rays soon penetrate any covering in which the plate may be wrapped to protect it from ordinary light rays. The process of taking a shadowgraph may therefore be conducted in broad daylight, which is under certain conditions a great advantage, though the sensitiveness of plates exposed to Röntgen rays entails special care being taken of them when they are not in use. In the early days of X-radiography an exposure of some minutes was necessary to secure a negative, but now, thanks to the improvements in the tubes, a few seconds is often sufficient.

The discovery of the X-rays is a great discovery, because it has done much to promote the noblest possible cause, the alleviation of human suffering. Not everybody will appreciate a more rapid mode of telegraphy, or a new method of spinning yarn, but the dullest intellect will give due credit to a scientific process that helps to save life and limb. Who among us is not liable to break an arm or leg, or suffer from internal injuries invisible to the eye? Who among us therefore should not be thankful on reflecting that, in event of such a mishap, the X-rays will be at hand to show just what the trouble is, how to deal with it, and how far the healing advances day by day? The X-ray apparatus is now as necessary for the proper equipment of a hospital as a camera for that of a photographic studio.

It is especially welcome in the hospitals which accompany an army into the field. Since May 1896 many a wounded soldier has had reason to bless the patient work that led to the discovery at Würzburg. The Greek war, the war in Cuba, the Tirah campaign, the Egyptian campaign, and the war in South Africa, have given a quick succession of fine opportunities for putting the new photography to the test. There is now small excuse for the useless and agonising probings that once added to the dangers and horrors of the military hospital. Even if the X-ray equipment, by reason of its weight, cannot conveniently be kept at the front of a rapidly moving army, it can be set up in the "advanced" or "base" hospitals, whither the wounded are sent after a first rough dressing of their injuries. The medical staff there subject their patients to the searching rays, are able to record the exact position of a bullet or shell-fragment, and the damage it has done; and by promptly removing the intruder to greatly lessen its power to harm.

The Röntgen ray has added to the surgeon's armoury a powerful weapon. Its possibilities are not yet fully known, but there can be no doubt that it marks a new epoch in surgical work. And for this reason Professor Röntgen deserves to rank with Harvey, the discoverer of the blood's circulation; with Jenner, the father of vaccination; and with Sir James Young Simpson, the first doctor to use chloroform as an anæsthetic.

PHOTOGRAPHY IN THE DARK.

Strange as it seems to take photographs with invisible rays, it is still stranger to be able to affect sensitised plates without apparently the presence of any kind of rays.

Professor W. J. Russell, Vice-President of the Royal Society of London, discovered that many substances have the power of impressing their outlines automatically on a sensitive film, if the substance be placed in a dark cupboard in contact with, or very close to a dry-plate.

After some hours, or it may be days, development of the plate will reveal a distinct impression of the body in question. Dr. Russell experimented with wood, metal, leaves, drawings, printed matter, lace. Zinc proved to be an unusually active agent. A plate of the metal, highly polished and then ruled with patterns, had at the end of a few days imparted a record of every scratch and mark to the plate. And not only will zinc impress itself, but it affects substances which are not themselves active, throwing shadowgraphs on to the plate. This was demonstrated with samples of lace, laid between a plate and a small sheet of bright zinc; also with a skeleton leaf. It is curious that while the interposition of thin films of celluloid, gutta-percha, vegetable parchment, and gold-beater's skin—all inactive—between the zinc and the plate has no obstructive effect, a plate of thin glass counteracts the action of the zinc. Besides zinc, nickel, aluminium, pewter, lead, and tin among the metals influence a sensitised plate. Another totally different substance, printer's ink, has a similar power; or at least some printer's ink, for Professor Russell found that different samples varied greatly in their effects. What is especially curious, the printed matter on *both sides* of a piece of newspaper appeared on the plate, and that the effect proceeded from the ink and not from any rays passing from beyond it is proved by the fact that the type came out *dark* in the development, whereas if it had been a case of shadowgraphy, the ink by intercepting rays would have produced *white* letters. Professor Russell has also shown that modern writing ink is incapable of producing an impression unaided, but that on the other hand paper written on a hundred years ago or a printed book centuries old will, with the help of zinc, yield a picture in which even faded and uncertain characters appear quite distinctly. This opens the way to a practical use of the discovery, in the deciphering of old and partly obliterated manuscripts.

A very interesting experiment may be made with that useful possession—a five-pound note. Place the note printed side next to the plate, and the printing appears dark; but insert the note between a zinc sheet and the plate, its back being this time towards the sensitised surface, and the printing appears *white;* and the zinc, after contact with the printed side, will itself yield a picture of the inscription as though it had absorbed some virtue from the note!

This is no doubt due to the fact that certain substances give off rays of a quite different character from ordinary light. It cannot be due to the emission of mere vapours, since the interposition of some quite air-proof substances between the zinc and the plate do not prevent its action.

Professor Niewenglowski, a Russian scientist, found that certain phosphorescent substances could affect a photographic plate through a thin sheet of aluminium but not through glass. He put a plate under a thin aluminium sheet, then upon that he laid a small square of glass, and upon that some calcium sulphide. On developing that plate, after the whole pile had lain in the dark for twenty-four hours, he found a picture of the glass square on the plate.

Professor Becquerel of Paris carried this experiment further, trying other substances, including some salts of Uranium, which ultimately led to the discovery by Madame Curie of the marvellous substance Radium.

This sends forth rays identical with the X-rays, by which most wonderful pictures can be taken. The writer has seen one obtained by placing some pieces of lead wire upon a plate; then over that a deal board, with a solid lump of granite 6 inches thick upon it. On the top of the granite a tiny quantity of radium salts was placed, with the result that a picture of the lead wire was obtained.

SOLAR MOTORS.

ONE day George Stephenson and a friend stood watching a train drawn by one of his locomotives.

"What moves that train?" asked Stephenson.

"The engine," replied his friend.

"And what moves the engine?"

"The steam."

"And what produces the steam?"

"Coal."

"And what produces coal?"

This last query nonplussed his friend, and Stephenson himself replied, "The sun."

The "bottled sunshine" that drove the locomotive was stored up millions of years ago in the dense forests then covering the face of the globe. Every day vegetation was built by the sunbeams, and in the course of ages this growth was crushed into fossil form by the pressure of high-piled rock and débris. To-day we cast "black diamonds" into our grates and furnaces, to call out the warmth and power that is a legacy from a period long prior to the advent of fire-loving man, often forgetful of its real source.

We see the influence of the sun more directly in the motions of wind and water. Had not the sun's action deposited snow and rain on the uplands of the world, there would be no roaring waterfall, no rushing torrent, no smooth-flowing stream. But for the sun heating the atmosphere unequally, there would not be that rushing of cool air to replace hot which we know as wind.

We press Sol into our service when we burn fuel; our wind-mills and water-mills make him our slave. Of late years many prophets have arisen to warn us that we must not be too lavish of our coal; that the time is not so far distant, reckoning by centuries, when the coal-seams of the world will be worked out and leave our descendants destitute of what plays so important a part in modern life. Now, though waste is unpardonable, and the care for posterity praiseworthy, there really seems to be no good reason why we should alarm ourselves about the welfare of the people of the far future. Even if coal fails, the winds and the rivers will be there, and the huge unharnessed energy of the tides, and the sun himself is ready to answer appeals for help, if rightly shaped. He does not demand the prayers of Persian fire-worshippers, but rather the scientific gathering of his good gifts.

Place your hand on a roof lying square to the summer sun, and you will find it too hot for the touch. Concentrate a beam of sunshine through a small burning-glass. How fierce is the small glowing focal spot that makes us draw our hands suddenly away! Suppose now a large glass many feet across bending several square yards of sun rays to a point, and at that point a boiler. The boiler would develop steam, and the steam might be led into cylinders and forced to drudge for us.

Do many of us realise the enormous energy of a hot summer's day? The heat falling in the tropics on a single square foot of the earth's surface has been estimated as the equivalent of one-third of a horse-power. The force of Niagara itself would on this basis be matched by the sunshine streaming on to a square mile or so. A steamship might be propelled by the heat that scorches its decks.

For many centuries inventors have tried to utilise this huge waste power. We all know how, according to the story, Archimedes burnt up the Roman ships besieging his native town, Syracuse, by concentrating on them the sun heat cast from hundreds of mirrors. This story is less probable than interesting as a proof that the ancients were aware of the sun's power. The first genuine solar machine was the work of Ericsson, the builder of the *Monitor*. He focused sun heat on a boiler, which gave the equivalent of one horse-power for every hundred square feet of mirrors employed. This was not what engineers would call a "high efficiency," a great deal of heat being wasted, but it led the way to further improvements.

In America, especially in the dry, arid regions, where fuel is scarce and the sun shines pitilessly day after day, all the year round, sun-catchers of various types have been erected and worked successfully.

Dr. William Calver, of Washington, has built in the barren wastes of Arizona huge frames of mirrors, travelling on circular rails, so that they may be brought to face the sun at all hours between sunrise and sunset. Dr. Calver employs no less than 1600 mirrors. As each of these mirrors develops 10–15 degrees of heat it is obvious, after an appeal to simple arithmetic, that the united efforts of these reflectors should produce the tremendous temperature 16,000–24,000 degrees, which, expressed comparatively, means the paltry 90 degrees in the shade beneath which we grow restive multiplied hundreds of times. Hitherto the greatest known heat had been that of the arc of the electric lamp, in which the incandescent particles between pole and pole attain 6000 degrees Fahrenheit.

The combined effect of the burning mirrors is irresistible. They can, we are told, in a few moments reduce Russian iron to the consistency of warmed wax, though it mocks the heat of many blast-furnaces. They will bake bricks twenty times as rapidly as any kiln; and the bricks produced are not the friable blocks which a mason chips easily with his trowel, but bodies so hard as to scratch case-hardened steel.

There are at work in California sun-motors of another design. The reader must imagine a huge conical lamp-shade turned over on to its smaller end, its inner surface lined with nearly 1800 mirrors 2 feet long and 3 inches broad, the whole supported on a light iron framework, and he will have a good idea of the apparatus used on the Pasadena ostrich farm. The machine is arranged at right angles to the path of the sun, in such a manner that it follows all day long, by the agency of clockwork. In the focus of the mirrors is a boiler, 13 feet 6 inches long, coated with black, heat-absorbing substances. This boiler holds over 100 gallons of water, and being fed automatically will raise steam untended all the day through. The steam is led by pipes to an engine working a pump, capable of delivering 1400 gallons per minute.

The cheapness of the apparatus in proportion to its utility is so marked that, in regions where sunshine is almost perpetual, the solar motor will in time become as common as are windmills and factory chimneys elsewhere. If the heat falling on a few square yards of mirror lifts nearly 100,000 gallons of water an hour, there is indeed hope for the Sahara, the Persian Desert, Arabia, Mongolia, Mexico, Australia. That is to say, if the water under the earth be in these parts as plentiful as the sunshine above it. The effect of water on the most unpromising soil is marvellous. Already in Algeria the French have reclaimed thousands of square miles by scientific irrigation. In Australia huge artesian wells have made habitable for man and beast millions of acres that were before desert.

It is only a just retribution that the sun should be harnessed and compelled to draw water for tracts to which he has so long denied it. The sun-motor is only just entering on its useful career, and at present we can but dream of the great effects it may have on future civilisation. Yet its principle is so simple, so scientific, and so obvious, that it is easy to imagine it at no far distant date a dangerous rival to King Coal himself. To quarry coal from the bowels of the earth and transform it into heat, is to traverse two sides of a triangle, the third being to use the sunshine of the passing hour.

LIQUID AIR.

AMONG common phenomena few are more interesting than the changes undergone by the substance called water. Its usual form is a liquid. Under the influence of frost it becomes hard as iron, brittle as glass. At the touch of fire it passes into unsubstantial vapour.

This transformation illustrates the great principle that the form of every substance in the universe is a question of heat. A metal transported from the earth to the sun would first melt and then vaporise; while what we here know only as vapours would in the moon turn into liquids.

We notice that, as regards bulk, the most striking change is from liquid to gaseous form. In steam the atoms and molecules of water are endowed with enormous repulsive vigour. Each atom suddenly shows a huge distaste for the company of its neighbours, drives them off, and endeavours to occupy the largest possible amount of private space.

Now, though we are accustomed to see water-atoms thus stirred into an activity which gives us the giant steam as servant, it has probably fallen to the lot of but few of us to encounter certain gaseous substances so utterly deprived of their self-assertiveness as to collapse into a liquid mass, in which shape they are quite strangers to us. What gaseous body do we know better than the air we breathe? and what should we less expect to be reducible to the consistency of water? Yet science has found that by cold and pressure this change may be brought about, and the arts have found uses for this remarkable liquid. Who would expect that the bright light of the kinematograph is often due to liquid air? But of that more presently.

Very likely our readers have sometimes noticed a porter uncoupling the air-tube between two railway carriages. He first turns off the tap at each end of the tube, and then by a twist disconnects a joint in the centre. At the moment of disconnection what appears to be a small cloud of steam issues from the joint. This is, however, the result of cold, not heat, the tube being full of highly-compressed air, which by its sudden expansion develops cold sufficient to freeze any particles of moisture in the surrounding air.

Keep this in mind, and also what happens when you inflate your cycle-tyre. The air-pump grows hotter and hotter as inflation proceeds: until at last, if of metal, it becomes uncomfortably warm. The heat is caused by the forcing together of air-molecules, and inasmuch as all force produces heat, your strength is transformed into warmth.

In these two operations, compression and expansion, we have the key to the creation of liquid air—the great power, as some say, of to-morrow.

Liquid Air

Suppose we take a volume of air and squeeze it into $\frac{1}{100}$ of its original space. The combativeness of the air-atoms is immensely increased. They pound each other frantically, and become very hot in the process. Now, by cooling the vessel in which they are, we rob them of their energy. They become quiet, but they are much closer than before. Then imagine that all of a sudden we let them loose again. The life is gone out of them, their heat has departed, and on separating they shiver grievously. In other words, the heat contained by the $\frac{1}{100}$ volume is suddenly compelled to "spread itself thin" over the whole volume: result—intense cold. And if this air be brought to bear upon a second vessel filled likewise with compressed air, the cold will be even more intense, until at last the air-atoms lose all their strength and collapse into a liquid.

Liquid air is no new thing. Who first made it is uncertain. The credit has been claimed for several people, among them Olzewski, a Pole, and Pictet, a Swiss. As a mere laboratory experiment the manufacture of liquid air in small quantities has been known for twenty years or more. The earlier process was one of terrific compression alone, actually forcing the air molecules by sheer strength into such close contact that their antagonism to one another was temporarily overcome. So expensive was the process that the first ounce of liquid air is estimated to have cost over £600!

In order to make liquid air an article of commerce the most important condition was a wholesale decrease in cost of production. In 1857 C. W. Siemens took out a patent for making the liquid on what is known as the regenerative principle, whereby the compressed air is chilled by expanding a part of it. Professor Dewar—a scientist well known for his researches in the field of liquid gases—had in 1892 produced liquid air by a modification of the principle at comparatively small cost; and other inventors have since then still further reduced the expense, until at the present day there is just a possibility of liquid air becoming cheap enough to prove a dangerous rival to steam and electricity.

It will be interesting to see how this strange liquid is made on a huge scale. First the air has to be compressed, an operation which is performed by a compressor, a machine very much like a steam engine reversed. In fact, the writer knows an engineering works where at this moment an ex-steam engine is at work as an air-compressor, though not for making liquid air. Imagine a cylinder with a piston inside it, and with the usual piston-rod, connecting-rod, crank, and fly-wheel. Place a driving belt upon the fly-wheel and so turn it round; the piston will then be forced to and fro, and if suitable valves be provided it will alternately suck in air and force it out again. When the pressure required is great, water is made to flow around the cylinder to keep it cool, for, as has already been explained, the expenditure of force always generates heat, and so compressing air causes the cylinder to become very hot. Moreover, for the same reason, the compression is not done all at once in one cylinder, but stage by stage in several. Thus the heat generated is divided between them all instead of being all in one.

The air having thus been compressed passes into the liquid-air machine proper. The essential part of this is a coil of copper pipe, which the air enters at the top and through which it slowly passes downwards. At the bottom it escapes, and of course at once expands, its temperature falling accordingly. The first air which thus escapes passes up inside the vessel which forms the outer case of the machine, among the coils of pipe, so cooling the following air which is then on its way down. There is thus compressed and comparatively hot air passing down inside the tube, and expanded and comparatively cold air passing upwards outside it. The second lot of air which reaches the outlet is therefore colder than the first, for the previously liberated air has cooled it on its way. Thus the second lot of air liberated is colder than the first, and it in its turn makes the third lot colder still. For clearness' sake we have spoken of the various "lots" of air, but the process is really continuous, and what with the cooling which it undergoes while descending the tube and the cooling caused by its liberation, the air ultimately becomes so cold that instead of coming out as air it flows out a steely blue liquid, very much like very pure water.

The vaporous air has been condensed by co into liquid air, just as vaporous water (steam) becomes liquid water under conditions with which we are familiar. The difference between the two is that while the boiling-point of water is 212 degrees *above* zero, that of liquid air is 312 degrees *below* zero—the boiling-point, be it remembered, being of course the temperature at which the liquid boils and rapidly turns into vapour.

Thus our ordinary temperatures are sufficient to make liquid air boil. Pour some on to a block of ice and the result is just like pouring water on to a hot fire. The liquid bubbles and boils, splutters and fumes, finally disappearing entirely, having returned to its normal terrestrial condition—just air.

You may dip your finger into a vessel of it—if you withdraw it again quickly—without hurt. The cushion of air that your finger takes in with it protects you against harm—for a moment. But if you held it in the liquid for a couple of seconds you would be minus a digit. Pour a little over your coat sleeve. It flows harmlessly to the ground, where it suddenly expands into a cloud of chilly vapour.

Put some in a test tube and cork it up. The cork soon flies out with a report—the pressure of the boiling air drives it. Now watch the boiling process. The nitrogen being more volatile—as it boils at a lower temperature than oxygen—passes off first, leaving the pure, blue oxygen. The temperature of this liquid is over 312 degrees below zero (as far below the temperature of the air we breathe as the temperature of molten lead is above it!). A tumbler of liquid oxygen dipped into water is soon covered with a coating of ice, which can be detached from the tumbler and itself used as a cup to hold the liquid. If a bit of steel wire be now twisted round a lighted match and the whole dipped into the cup, the steel flares fiercely and fuses into small pellets; which means that an operation requiring 3000 degrees Fahrenheit has been accomplished in a liquid 300 degrees below zero!

Liquid air has curious effects upon certain substances. It makes iron so brittle that a ladle immersed for a few moments may be crushed in the hands; but, curiously enough, it has a toughening effect on copper and brass. Meat, eggs, fruit, and all bodies containing water become hard as steel and as breakable as glass. Mercury is by it congealed to the consistency of iron; even alcohol, that can brave the utmost Arctic cold, succumbs to it. The writer was present when some thermometers, manufactured by Messrs. Negretti and Zambra, were tested with liquid air. The spirit in the tubes rapidly descended to 250 degrees below zero, then sank slowly, and at about 260 degrees froze and burst the bulb. The measuring of such extreme temperatures is a very difficult matter in consequence of the inability of spirit to withstand them, and special apparatus, registering cold by the shrinkage of metal, must be used for testing some liquid gases, notably liquid hydrogen, which is so much colder than liquid air that it actually freezes it into a solid ice form!

For handling and transporting liquid gases glass receptacles with a double skin from which all air has been exhausted are employed. The surrounding vacuum is so perfect an insulator that a "Dewar bulb" full of liquid air scarcely cools the hand though the intervening space is less than an inch. This piece of scientific apparatus has now found a use in ordinary affairs of life under the name of "Vacuum Flask." The same vacuum which keeps the heat of the atmosphere from penetrating to the liquid air will keep our coffee hot by preventing its heat from escaping into the atmosphere. The vacuum is a barrier through which heat cannot pass either way.

One use at least for liquid air is sufficiently obvious. As a refrigerating agent it is unequalled. Bulk for bulk its effect is of course far greater than that of ice; and it has this advantage over other freezing compounds, that whereas slow freezing has a destructive effect upon the tissues of meat and fruit, the instantaneous action of liquid air has no bad results when the thing frozen is thawed out again. It was at one time proposed to erect depôts at large ports for supplying ships, to preserve the food, cool the cabins in the tropics, and, erhaps, to alleviate some of the horrors of the stokehold.

Liquid air is already used in medical and surgical science. In surgery it is substituted for anæsthetics, deadening any part of the body on which an operation has to be performed. In fever hospitals, too, its cooling influence will be welcomed; and liquid xygen takes the place of compressed oxygen for viving the flickering flame of life. It may also ve invaluable for divers and submarine boats.

n combination with oil and charcoal liquid air, der the name of "oxyliquit," becomes a powerful asting agent. Cartridges of paper filled with the il and charcoal are provided with a firing primer. When everything is ready for the blasting the cartridges are dropped into a vessel full of liquid air, saturated, placed in position, and exploded. The writer has been assured that oxyliquit is twice as powerful as nitro-glycerine, and its cost but one-third of that of the other explosive. It is also safer to handle, for in case of a misfire the cartridge becomes harmless in a few minutes, after the liquid air has evaporated.

It was hoped at one time that liquid air might be used as a method of storing power. It is like a mighty compressed spring. Power liquefied it: low but the gentlest heat to get at it and it expands ack to its vaporous form, giving back power in e process, just as steam does when water is aporated in a boiler. An engine constructed for steam would work just as well with the vapour given off by liquid air. Such an arrangement would indeed be in all respects like a steam plant except that no fire would be needed, since the natural heat of all things on the earth's surface would do instead.

It would be an ideal form of power, but unfortunately, as so often happens, the question of cost upsets it all. The cost of making the liquid is too heavy. If at some future time the process could be cheapened by making some use of all that waste heat which is generated and is carried away in the cooling water, then liquid air may be a very handy way of storing and conveying power.

Its chief commercial use is in the manufacture of oxygen for providing the limelight for magic lanterns and kinematograph apparatus, and for the many manufacturing processes in which oxygen plays a part. As has been mentioned already the nitrogen boils at a higher temperature than the oxygen, and so if a quantity of liquid air be allowed to boil the nitrogen boils off first. This is allowed to escape, but as soon as the oxygen begins to vaporise it is collected, compressed into steel bottles, and sold.

It would be a pity to close this chapter without pointing out how the manufacture of liquid air exemplifies all the methods of producing artificial cold. Artificial ice is an ordinary article of commerce, cold storage on ships and in warehouses on shore for the conveyance and keeping of meat and other perishable foods is quite a commonplace of modern life. And all this is done on the same principle.

In every case a gas is used for the working substance. In some plants it is carbonic acid, in others it is the vapour of ammonia. It is first compressed by a pump, then it is passed through a condenser, an arrangement of tubes around which cold water circulates. From that it passes to the refrigerator, more tubes, in which it is allowed to expand and therefore to cool further. Around the tubes of the refrigerator there circulates a non-freezable liquid called "brine," which is cooled by contact with the tubes, and which then circulates through other pipes in the storage chamber, carrying with it its load, as we might call it, of intense cold, just as the hot liquid in the heating pipes carries heat to all parts of a public building.

HORSELESS CARRIAGES.

A BODY of enterprising Manchester merchants, in the year 1754, put on the road a "flying coach," which, according to their special advertisement, would, "however incredible it may appear, actually, barring accidents, arrive in London in four and a half days after leaving Manchester." According to the Lord Chancellor of the time such swift travelling was considered dangerous, as well as wonderful—the condition of the roads might well make it so—and also injurious to health. "I was gravely advised," he says, "to stay a day in York on my journey between Edinburgh and London, as several passengers who had gone through without stopping had died of apoplexy from the rapidity of the motion."

As the coach took a fortnight to pass from the Scotch to the English capital, at an average pace of between three and four miles an hour, it is probable that the Chancellor's advisers would be very seriously indisposed by the mere sight of a motor-car whirling along in its attendant cloud of dust, could they be resuscitated for the purpose. And we, on the other hand, should prefer to get out and walk to "flying" at the safe speed of their mail coaches.

Horseless Carriages

The improvement of highroads, and road-making generally, accelerated the rate of posting. In the first quarter of the nineteenth century an average of ten or even twelve miles an hour was maintained on the Bath Road. But that pace was considered inadequate when the era of the "iron horse" commenced, and the decay of stage-driving followed hard upon the growth of railways. What should have been the natural successor of the stage-coach was driven from the road by ill-advised legislation, giving the railroads a monopoly of swift transport, which was not removed until 1896.

The history of the steam-coach, steam-carriage, automobile, motor-car—to give it its successive names—is in a manner unique, showing as it does, instead of steady development of a practical means of locomotion, a sudden and decisive check to an invention worthy of far better treatment than it received. The compiler of even a short survey of the automobile's career is obliged to divide his account into two main portions, linked together by a few solitary engineering achievements.

The first period (1800–1836), will, without any desire to arrogate for England more than her due or to belittle the efforts of any other nations, be termed the English period, since in it England took the lead, and produced by far the greatest number of steam-carriages. The second (1870 to the present day) may, with equal justice, be styled the Continental period, as witnessing the great developments made in automobilism by French, German, Belgian, and American engineers: England, for reasons that will be presently noticed, being for some time too heavily handicapped to take a part in the advance.

Historical.—It is impossible to discover who made the first self-moving carriage. In the sixteenth century one Johann Haustach, a Nuremberg watchmaker, produced a vehicle that derived its motive power from coiled springs, and was in fact a large edition of our modern clockwork toys. About the same time the Dutch, and among them especially one Simon Stevin, fitted carriages with sails, and there are records of a steam-carriage as early as the same century.

But the first practical, and at least semi-successful, automobile driven by internal force was undoubtedly that of a Frenchman, Nicholas Joseph Cugnot, who justly merits the title of father of automobilism. His machine, which is to-day one of the most treasured exhibits in the Paris Museum of Arts and Crafts, consisted of a large carriage, having in front a pivoted platform bearing the machinery, and resting on a solid wheel, which propelled as well as steered the vehicle. The boiler, of stout riveted copper plates, had below it an enclosed furnace, from which the flames passed upwards through the water through a funnel. A couple of cylinders, provided with a simple reversing gear, worked a ratchet that communicated motion to the driving-wheel. This carriage did not travel beyond a very slow walking pace, and

Cugnot therefore added certain improvements, after which (1770) it reached the still very moderate speed of four miles an hour, and distinguished itself by charging and knocking down a wall, a feat that is said to have for a time deterred engineers from developing a seemingly dangerous mode of progression.

Ten years later Dallery built a steam car, and ran it in the streets of Amiens—we are not told with what success; and before any further advance had been made with the automobile the French Revolution put a stop to all inventions of a peaceful character among our neighbours.

In England, however, steam had already been recognised as the coming power. Richard Trevethick, afterwards to become famous as a railroad engineer, built a steam motor in 1802, and actually drove it from Cambourne to Plymouth, a distance of ninety miles. But instead of following up this success, he forsook steam-carriages for the construction of locomotives, leaving his idea to be expanded by other men, who were convinced that a vehicle which could be driven over existing roads was preferable to one that was helpless when separated from smooth metal rails. Between the years 1800 and 1836 many steam vehicles for road traffic appeared from time to time, some, such as David Gordon's (propelled by metal legs pressing upon the ground), strangely unpractical, but the majority showing a steady improvement in mechanical design.

As it will be impossible, without writing a small book, to name all the English constructors of this period, we must rest content with the mention of the leading pioneers of the new locomotion.

Sir Goldsworthy Gurney, an eminent chemist, did for mechanical road propulsion what George Stephenson was doing for railway development. He boldly spent large sums on experimental vehicles, which took the form of six-wheeled coaches. The earliest of these were fitted with legs as well as driving-wheels, since he thought that in difficult country wheels alone would not have sufficient grip. (A similar fallacy was responsible for the cogged wheels on the first railways.) But in the later types legs were abandoned as unnecessary. His coaches easily climbed the steepest hills round London, including Highgate Hill, though a thoughtful mathematician had proved by calculations that a steam-carriage, so far from mounting a gradient, could not, without violating all natural laws, so much as move itself on the level!

Having satisfied himself of their power, Gurney took his coaches further afield. In 1829 was published the first account of a motor trip made by him and three companions through Reading, Devizes, and Melksham. The pace was, we read, at first only about six miles an hour, including stoppages. They drove very carefully to avoid injury to the persons or feelings of the country folk; but at Melksham, where a fair was in progress, they had to face a shower of stones, hurled by a crowd of roughs at the instigation of some coaching postilions, who feared losing their livelihood if the new method of locomotion became general. Two of the tourists were severely hurt, and Gurney was obliged to take shelter in a brewery, where constables guarded his coach. On the return journey the party timed their movements so as to pass through Melksham while the inhabitants were all safely in bed.

The coach ran most satisfactorily, improving every mile. "Our pace was so rapid," wrote one of the company, "that the horses of the mail-cart which accompanied us were hard put to it to keep up with us. At the foot of Devizes Hill we met a coach and another vehicle, which stopped to see us mount this hill, an extremely steep one. We ascended it at a rapid rate. The coach and passengers, delighted at this unexpected sight, honoured us with shouts of applause."

In 1830 Messrs. Ogle and Summers completely beat the road record on a vehicle fitted with a tubular boiler. This car, put through its trials before a Special Commission of the House of Commons, attained the astonishing speed of 35 miles an hour on the level, and mounted a hill near Southampton at 24½ miles an hour. It worked at a boiler pressure of 250 lbs. to the square inch, and though not hung on springs, ran 800 miles without a breakdown. This performance appears all the more extraordinary when we remember the roads of that day were not generally as good as they are now, and that in the previous year Stephenson's "Rocket," running on rails, had not reached a higher velocity.

The report of the Parliamentary Commission on horseless carriages was most favourable. It urged that the steam-driven car was swifter and lighter than the mail-coaches; better able to climb and descend hills; safer; more economical; and less injurious to the roads; and, in conclusion, that the heavy charges levied at the toll-gates (often twenty times those on horse vehicles) were nothing short of iniquitous.

As a result of this report, motor services, inaugurated by Walter Hancock, Braithwayte, and others, commenced between Paddington and the Bank, London and Greenwich, London and Windsor, London and Stratford. Already, in 1829, Sir Charles Dance had a steam-coach running between Cheltenham and Gloucester. In four months it ran 3500 miles and carried 3000 passengers, traversing the nine miles in three-quarters of an hour; although narrow-minded landowners placed ridges of stone eighteen inches deep on the road by way of protest.

The most ambitious service of all was that between London and Birmingham, established in 1833 by Dr. Church. The rolling-stock consisted of a single very much decorated coach.

The success of the road-steamer seemed now assured, when a cloud appeared on the horizon. It had already been too successful. The railway companies were up in arms. They saw plainly that if once the roads were covered with vehicles able to transport the public at low fares quickly from door to door on existing thoroughfares, the construction of expensive railroads would be seriously hindered, if not altogether stopped. So, taking advantage of two motor accidents, the companies appealed to Parliament—full of horse-loving squires, and manufacturers who scented profit in the railways—and though scientific opinion ran strongly in favour of the steam-coach, a law was passed in 1836 which rendered the steamers harmless by robbing them of their speed. The fiat went forth that in future *every road locomotive should be preceded at a distance of a hundred yards by a man on foot carrying a red flag to warn passengers of its approach.* This law marks the end of the first period of automobilism as far as England is concerned. At one blow it crippled a great industry, deprived the community of a very valuable means of transport, and crushed the energies of many clever inventors who would soon, if we may judge by the rapid advances already made in construction, have brought the steam-carriage to a high pitch of perfection. In the very year in which they were suppressed the steam services had proved their efficiency and safety. Hancock's London service alone traversed 4200 miles without serious accident, and was so popular that the coaches were generally crowded. It is therefore hard to believe that these vehicles did not supply a public want, or that they were regarded by those who used them as in any way inferior to horse-drawn coaches. Yet ignorant prejudice drove them off the road for sixty years; and to-day it surprises many Englishmen to learn that what is generally considered a novel method of travelling was already fairly well developed in the time of their grandfathers.

Second Period (1870 onwards).—To follow the further development of the automobile we must cross the Channel once again. French invention had not been idle while Gurney and Hancock were building their coaches. In 1835 M. Dietz established a service between Versailles and Paris, and the same year M. D'Asda carried out some successful trials of his steam "diligence" under the eyes of Royalty. But we find that for the next thirty-five years the steam-carriage was not much improved, owing to want of capital among its French admirers. No Gurney appeared, ready to spend his thousands in experimenting; also, though the law left road locomotion unrestricted, the railways offered a determined opposition to a possibly dangerous rival. So that, on the whole, road transport by steam fared badly till after the terrible Franco-Prussian war, when inventors again took courage. M. Bollée, of Mans, built in 1873 a car, "l'Obéissante," which ran from Mans to Paris; and became the subject of allusions in popular songs and plays, while its name was held up as an example to the Paris ladies. Three years later he constructed a steam omnibus to carry fifty persons, and in 1878 exhibited a car that journeyed at the rate of eighteen miles an hour from Paris to Vienna, where it aroused great admiration.

After the year 1880 French engineers divided their attention between the heavy motor omnibus and light vehicles for pleasure parties. In 1884 MM. Bouton and Trépardoux, working conjointly with the Comte de Dion, produced a steam-driven tricycle, and in 1887 M. Serpollet followed suit with another, fitted with the peculiar form of steam generator that bears his name. Then came in 1890 a very important innovation, which has made automobilism what it now is. Gottlieb Daimler, a German engineer, introduced the *petrol gas-motor.* Its comparative lightness and simplicity at once stamped it as the thing for which makers were waiting. Petrol-driven vehicles were soon abroad in considerable numbers and varieties, but they did not attract public attention to any great extent until, in 1894, M. Pierre Giffard, an editor of the *Petit Journal,* organised a motor race from Paris to Rouen. The proprietors of the paper offered handsome prizes to the successful competitors. There were ten starters, some on steam, others on petrol cars. The race showed that, so far as stability went, Daimler's engine was the equal of the steam cylinder. The next year another race of a more ambitious character was held, the course being from Paris to Bordeaux and back. Subscriptions for prizes flowed in freely. Serpollet, de Dion, and Bollée prepared steam cars that should win back for steam its lost supremacy, while the petrol faction secretly built motors of a strength to relegate steam once and for all to a back place. Electricity, too, made a bid unsuccessfully for the prize in the Jeantaud car, a special train being engaged in advance to distribute charged accumulators over the route. The steamers broke down soon after the start, so that the petrol cars "walked over" and won a most decisive victory.

The interest roused in the race led the Comte de Dion to found the Automobile Club of France, which drew together all the enthusiastic admirers of the new locomotion. Automobilism now became a sport, a craze. The French, with their fine straight roads, and a not too deeply ingrained love of horseflesh, gladly welcomed the flying car, despite its noisy and malodorous properties.

Orders flowed in so freely that the motor makers could not keep pace with the demand, or promise delivery within eighteen months. Rich men were therefore obliged to pay double prices if they could find any one willing to sell—a state of things that remains unto this day with certain makes of French cars. Poorer folks contented themselves with De Dion motor tricycles, which showed up so well in the 1896 Paris-Marseilles race; or with the neat little three-wheeled cars of M. Bollée. Motor racing became the topic of the hour. Journals were started for the sole purpose of recording the doings of motorists; and few newspapers of any popularity omitted a special column of motor news. Successive contests on the highroads at increasing speeds attracted increased interest. The black-goggled, fur-clad *chauffeur* who carried off the prizes found himself a hero.

Racing seems to be a necessary feature in the development of any special type of vehicle. Cycle races used to be all the rage. There were heroes of the cycle track who rivalled famous cricketers and footballers in the public estimation. Others raced on the public roads. The contests were both as to speed and also for endurance. Twenty-four-hour rides along the Great North Road were a common and much-talked-of event. All such things are past now that the bicycle has settled down into an indispensable feature of modern life. Statistics seem to show that one machine is in use in Great Britain for every fifteen people. When we leave out the babies, the old people, the invalids, and the very poor who cannot afford a bicycle, we see that nearly everyone has the use of one.

In the same way the motor races which heralded the advent of the motor car had their day. Having served their purpose of advertising what the motor car could do and, by pitting one against another, spurring on the manufacturers to improve and improve, they have dropped too. Tests of reliability and other serious functions of that kind are still carried out, but the spectacular kind of racing has gone for ever. Road-racing went specially quickly, because of the terrible accidents which occurred, but even racing upon a track has largely gone out of fashion. The great motor-track at Brooklands, for example, is now better known for its exhibitions of flying than for its motor races.

And just as the end of the cycle races signified the bicycle's accession to a definite place in modern life, so has the end of the motor race denoted that the motor is an essential feature of the life of to-day and recognised as such.

The value of racing in the early stages of the motor-car's history is shown by the remarkable strides made during a short time. Particularly so was this the case in France, where many of the main roads are wide and straight—just the places for motor races.

The growth of speed in the French races is remarkable. In 1894 the winning car ran at a mean velocity of thirteen miles an hour; in 1895, of fifteen. The year 1898 witnessed a great advance to twenty-three miles, and the next year to thirty miles. But all these speeds paled before that of the Paris to Bordeaux race of 1901, in which the winner, M. Fournier, traversed the distance of 327½ miles at a rate of 53¾ miles per hour! The famous Sud express, running between the same cities, and considered the fastest long-distance express in the world, was beaten by a full hour. It is interesting to note that in the same races a motor bicycle, a Werner, weighing 80 lbs. or less, successfully accomplished the course at an average rate of nearly thirty miles an hour. The

A Modern Motor Bicycle. A well-known rider on his Phelon and Moore Motor Bicycle with 3½ horse-power engine.

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motor-car, after waiting seventy years, had had its revenge on the railways.

This was not the only occasion on which an express service showed up badly against its nimble rival of the roads. In June, 1901, the French and German authorities forgot old animosities in a common enthusiasm for the automobile, and organised a race between Paris and Berlin. It was to be a big affair, in which the cars of all nations should fight for the speed championship. Every possible precaution was taken to insure the safety of the competitors and the spectators. Flags of various colours and placards marked out the course, which lay through Rheims, Luxembourg, Coblentz, Frankfurt, Eisenach, Leipsic, and Potsdam to the German capital. About fifty towns and large villages were "neutralised"—that is to say, the competitors had to consume a certain time in traversing them. At the entrance to each neutralised zone a "control" was established. As soon as a competitor arrived, he must slow down, and a card on which was written the time of his arrival was handed to a "pilot," who cycled in front of the car to the other "control" at the farther end of the zone, from which, when the proper time had elapsed, the car was dismissed. Among other rules were: that no car should be pushed or pulled during the race by any one else than the passengers; that at the end of the day only a certain time should be allowed for cleaning and repairs; and that a limited number of persons, varying with the size of the car, should be permitted to handle it during that period.

A small army of automobile club representatives, besides thousands of police and soldiers, were distributed along the course to restrain the crowds of spectators. It was absolutely imperative that for vehicles propelled at a rate of from 50 to 60 miles an hour a clear path should be kept.

At dawn, on July 27th, 109 racing machines assembled at the Fort de Champigny, outside Paris, in readiness to start for Berlin. Just before half-past three, the first competitor received the signal; two minutes later the second; and then at short intervals for three hours the remaining 107, among whom was one lady, Mme. de Gast. At least 20,000 persons were present, even at that early hour, to give the racers a hearty farewell, and demonstrate the interest attaching in France to all things connected with automobilism.

Great excitement prevailed in Paris during the three days of the race. Every few minutes telegrams arrived from posts on the route telling how the competitors fared. The news showed that during the first stage at least a hard fight for the leading place was in progress. The French cracks, Fournier, Charron, De Knyff, Farman, and Girardot pressed hard on Hourgières, No. 2 at the starting-point. Fournier soon secured the lead, and those who remembered his remarkable driving in the Paris-Bordeaux race at once selected him as the winner.

Aix-la-Chapelle, 283 miles from Paris and the end of the first stage, was reached in 6 hours 28 minutes. Fournier first, De Knyff second by six minutes.

On the 28th the racing became furious. Several accidents occurred. Edge, driving the only English car, wrecked his machine on a culvert, the sharp curve of which flung the car into the air and broke its springs. Another ruined his chances by running over and killing a boy. But Fournier, Antony, De Knyff, and Girardot managed to avoid mishaps for that day, and covered the ground at a tremendous pace. At Dusseldorf Girardot won the lead from Fournier, to lose it again shortly. Antony, driving at a reckless speed, gained ground all day, and arrived a close second at Hanover, the halting-place, after a run averaging, in spite of bad roads and dangerous corners, no less than 54 miles an hour!

The *chauffeur* in such a race must indeed be a man of iron nerves. Through the great black goggles which shelter his face from the dust-laden hurricane set up by the speed he travels at he must keep a perpetual, piercingly keen watch. Though travelling at express speed, there are no signals to help him; he must be his own signalman as well as driver. He must mark every loose stone on the road, every inequality, every sudden rise or depression; he must calculate the curves at the corners and judge whether his mechanician, hanging out on the inward side, will enable a car to round a turn without slackening speed. His calculations and decisions must be made in the fraction of a second, for a moment's hesitation might be disaster. His driving must be furious and not reckless ; the timid *chauffeur* will never win, the careless one will probably lose. His head must be cool although the car leaps beneath him like a wild thing, and the wind lashes his face. At least one well-tried driver found the mere mental strain too great to bear, and retired from the contest ; and we may be sure that few of the competitors slept much during the nights of the race.

At four o'clock on the 29th Fournier started on the third stage, which witnessed another bout of fast travelling. It was now a struggle between him and Antony for first place. The pace rose at times to eighty miles an hour, a speed at which our fastest expresses seldom travel. Such a speed means huge risks, for stopping, even with the powerful brakes fitted to the large cars, would be a matter of a hundred yards or more. Not far from Hanover Antony met with an accident—Girardot now held second place ; and Fournier finished an easy first. All along the route crowds had cheered him, and hurled bouquets into the car, and wished him good speed ; but in Berlin the assembled populace went nearly frantic at his appearance. Fournier was overwhelmed with flowers, laurel wreaths, and other offerings ; dukes, duchesses, and the great people of the land pressed for presentations ; he was the hero of the hour.

Thus ended what may be termed a peaceful invasion of Germany by the French. Among other things it had shown that over an immense stretch of country, over roads in places bad as only German roads can be, the automobile was able to maintain an average speed superior to that of the express trains running between Paris and Berlin ; also that, in spite of the large number of cars employed in the race, the accidents to the public were a negligible quantity. It should be mentioned that the actual time occupied by Fournier was 16 hours 5 minutes ; that out of the 109 starters 47 reached Berlin ; and that Osmont on a motor cycle finished only 3 hours and 10 minutes behind the winner.

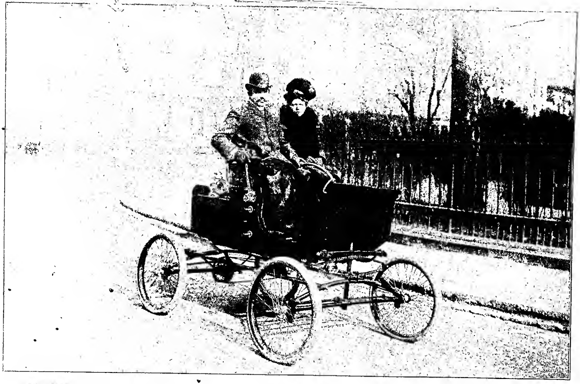
And not only did the new car quickly improve in speed, it also grew in reliability. The writer well remembers watching the progress of the great procession of motor vehicles from London to Brighton, organised to celebrate the removal of the old restrictions in November 1896. He stood at a point about a mile from the start, and even then, instead of a steady continuous procession, there were gaps left by those who had so soon fallen out. The whole road to Brighton was that day strewn with "lame ducks," which had for one cause or another broken down, and a mere handful reached the South Coast at all. There was a tendency to scoff at motor vehicles then, and this exhibition certainly did nothing to remove the tendency.

Yet only five years or so later a motor-car was careering about over the rough roads and tracks of

South Africa, and showing marvellous powers not only of durability but of adaptability to strange uses for which it was never intended. The following story taken from a report by Captain R. S. Walker, R.E., is full of interest.

"Several months ago I noticed a locomobile car at Cape Town, and being struck with its simplicity and neatness, bought it and took it up country with me, with a view to making some tests with it over bad roads, &c. Its first trip was over a rough course round Pretoria, especially chosen to find out defects before taking it into regular use. Naturally, as the machine was not designed for this class of work, there were several. In about a month these had all been found out and remedied, and the car was in constant use, taking stores, &c., round the towns and forts. It also performed some very useful work in visiting out-stations, where searchlights were either installed or wanted, and in this way visited nearly all the bigger towns in the Transvaal. It was possible to go round all the likely positions for a searchlight in one day at every station, which frequently meant considerably over fifty miles of most indifferent roads—more than a single horse could have been expected to do—and the car generally carried two persons on these occasions. The car was also used as a tender to a searchlight plant, on a gun-carriage and limber, being utilised to fetch gasolene, carbons, water, &c. &c., and also to run the dynamo for charging the accumulators used for sparking, thus saving running the gasolene motor for this purpose. To do this the trail of the carriage, on which was the dynamo, was lowered on to the ground, the back of the car was pulled up, one wheel being supported on the dynamo pulley and the other clear of the ground, and two bolts were passed through the balance-gear to join it. On one occasion the car ran a 30 c.m. searchlight for an hour, driving a dynamo in this way. In consequence of this a trailer has been made to carry a dynamo and projector for searchlighting in the field, but so far this has not been so used. The trailer hooks into an eye, passing just behind the balance-gear. A Maxim, Colt, or small ammunition cart, &c., could be attached to this same eye.

"Undoubtedly the best piece of work done by the car so far was its trial trip with the trailer, when it blew up the mines at Klein Nek. These mines were laid some eight months previously, and had never been looked to in the interval. There had been several bad storms, the Boers and cattle had been frequently through the Nek, it had been on fire, and finally it was shelled with lyddite. The mines, eighteen in number, were found to be intact except two, which presumably had been fired off by the heat of the veldt fire. All the insulation was burnt off the wires, and the battery was useless. It had been anticipated that a dynamo exploder would be inadequate to fire these mines, so a 250 volt two h.p. motor, which happened to be in Pretoria, weighing



By kind permission of] [*The Liquid Air Co.*

This graceful little motor car is driven by Liquid Air. It makes absolutely no smell or noise.

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about three or four hundredweight, was placed on the trailer; a quarter of a mile of insulated cable, some testing gear, the kits of three men and their rations for three days, with a case of gasolene for the car, were also carried on the car and trailer, and the whole left Pretoria one morning and trekked to Rietfontein. Two of us were mounted, the third drove the car. At Rietfontein we halted for the night, and started next morning with an escort through Commando Nek, round the north of the Magaliesburg, to near Klein Nek, where the road had to be left, and the car taken across country through bush veldt. At the bottom the going was pretty easy; only a few bushes had to be charged down, and the grass, &c., rather wound itself around the wheels and chain. As the rise became steeper the stones became very large, and the car had to be taken along very gingerly to prevent breaking the wheels. A halt was made about a quarter of a mile from the top of the Nek, where the mines were. These were reconnoitred, and the wire, &c., was picked up; that portion which was useless was placed on top of the charges, and the remainder taken to the car. The dynamo was slid off the trailer, the car backed against it; one wheel was raised slightly and placed against the dynamo pulley, which was held up to it by a man using his rifle as a lever; the other wheel was on the ground with a stone under it. The balance gear being free, the dynamo was excited without the other wheel moving, and the load being on for a very short time (that is, from the time of touching lead on dynamo terminal to firing of the mine) no harm could come to the car. When all the leads had been joined to the dynamo the car was started, and after a short time, when it was judged to have excited, the second terminal was touched, a bang and clouds of dust resulted, and the Klein Nek Minefield had ceased to exist. The day was extremely hot, and the work had not been light, so the tea, made with water drawn direct from the boiler, which we were able to serve round to the main body of our escort was much appreciated, and washed down the surplus rations we dispensed with to accommodate the battery and wire, which we could not leave behind for the enemy.

"On the return journey we found this extra load too much for the car, and had great difficulty getting up to Commando Nek, frequently having to stop to get up steam, so these materials were left at the first blockhouse, and the journey home continued in comfort.

"A second night at Rietfontein gave us a rest after our labour, and the third afternoon saw us on our way back to Pretoria. As luck would have it, a sandstorm overtook the car, which had a lively time of it. The storm began by blowing the sole occupant's hat off, so, the two mounted men being a long way behind, he shut off steam and chased his hat. In the meantime the wind increased, and the car sailed off 'on its own,' and was only just caught in time to save a smash. Luckily the gale was in the right direction, for the fire was blown out, and it was impossible to light a match in the open. The car sailed into a poort on the outskirts of Pretoria, got a tow from a friendly cart through it, and then steamed home after the fire had been relit.

"The load carried on this occasion (without the battery, &c.) must have been at least five hundredweight besides the driver, which, considering the car is designed to carry two on ordinary roads, and that these roads were by no means ordinary, was no mean feat. The car, as ordinarily equipped for trekking, carries the following: Blankets, waterproof sheets, &c., for two men; four planks for crossing ditches, bogs, stones, &c.; all necessary tools and spare parts, a day's supply of gasolene, a couple of telephones, and one mile of wire. In addition, on the trailer, if used for searchlighting: One 30 c.m. projector, one automatic lamp for projector, one dynamo (100 volts 20 ampères), two short lengths of wire, two pairs of carbons, tools, &c. This trailer would normally be carried with the baggage, and only picked up by the car when wanted as a light; that is, as a rule, after arriving in camp, when a good many other things could be left behind."

A later example still of both durability and speed occurred in 1908, when at Brooklands a man drove a car for twenty-four hours, covering in that time nearly 1582 miles, giving an average speed of just on 66 miles per hour. This is believed to be the greatest distance a man has ever travelled in twenty-four hours.

At the same place in 1909 a man covered half a mile, with a flying start, at the rate of nearly 128 miles per hour.

Such speeds as these belong to the exhibition period. No ordinary man in his senses wishes to move so fast. He does not want to face the risks —necessary risks. But they are interesting, just to show what can be done.

It is quite possible to dwell too much on the harm done by the silly restrictions which for so many years prevented the use of motor-cars in this country. As a matter of fact, they were removed as soon as it became evident that the new vehicle was really making strides in other countries. True they prevented us from taking our full share in the early stages of the development of the modern car, but it is quite likely that in any case we should have left this to others, following that national habit of ours referred to in another chapter. It is certainly the fact that at the present time there is little or nothing which foreign nations can teach us in the matter of building motor-cars. Great firms have sprung up, huge works have been erected, old decaying concerns have found new life and fresh prosperity, all through the manufacture of motor-cars. If anyone wants the best and most expensive, English firms make it for him. If he wants something cheap, he need not go outside England to get it. While at building the bodies of the cars, as distinct from the mechanism, the English are pre-eminent. For the heavier types of motor vehicle, such as motor buses, motor vans, and motor lorries, the English are unbeaten. And all that in spite of the handicap under which they suffered to commence with, when it was a crime to run one of the vehicles named along a public road.

The truth of the matter is that, apart from heavy and relatively slow vehicles, little progress could be made until the arrival of the petrol motor and the pneumatic tyre.

The petrol motor is really a little gas-engine and gas-works combined. The gas with which it is driven is derived from petrol, which in turn is obtained from petroleum.

Petroleum as it comes from the well is really a mixture of liquids, the distinguishing feature of each being the temperature at which it evaporates. These are separated by the process known as "fractional distillation." First a little heat is applied, and forthwith that part which vaporises most easily passes into gas, is collected, cooled, and condensed back into liquid. Then the heat is increased and another lot is distilled off, collected and condensed in another vessel. And so the process goes on until nothing but paraffin wax is left. Now the lightest of these liquids—the one, that is, which evaporates with the least heat—is called petrol or gasolene.

It evaporates at the ordinary temperatures of the atmosphere. A current of air passing over it is quite sufficient to carry it off in vapour. The carburettor, therefore, as the little "gas-works" is called, is simply a contrivance in which the petrol is squirted up in a tiny jet so as to form fine spray, while a current of air mingles with it, vaporises it very thoroughly, and finally carries it off into the cylinder of the motor.

The motor itself works, like all gas-engines, by means of periodical explosions inside a closed cylinder. One end of the cylinder is closed, while the other is open, a drum-shaped piston being free to slide to and fro inside it. So whenever an explosion occurs it tends to drive the piston outwards. But it is not easy to produce an explosion inside an enclosed vessel, and still more difficult is it to cause a succession of explosions. For an explosion is but the sudden expansion due to sudden burning, and so just as the smoke from a fire is capable of smothering the fire, so are the products of one explosion able to smother the next.

In the case of all gas-engines, therefore, it is first necessary to introduce into the cylinder some combustible gas well mixed with enough air to burn it properly. Then when that has been exploded the products of combustion must be ejected before the next charge comes in, for otherwise the latter would be so diluted that it would refuse to explode, or at any rate would explode very feebly. Another thing which has to be seen to in a gas-engine is that before the explosion takes place the gas must be compressed, as otherwise the explosion is weak.

So the working of a motor is very different from the straightforward pushing action of the steam in a steam-engine. Indeed, it seems at first sight as if it would be impossible to satisfy all these various needs in an engine without making it too complex. But really it is quite simple.

The piston moves outwards, and in so doing sucks in, as if it were a pump, a "charge" of gas and air properly mixed. Then it returns inwards, so that the second stroke compresses the charge into a small space at the back of the cylinder. Then that explodes and drives the piston outwards again. That makes the third stroke. Finally the piston moves inwards once more and pushes out the waste gases caused by the explosion. After that follows another charging stroke, and so the "cycle" of four strokes is repeated over and over again. It may be well, perhaps, to enumerate the strokes once more.

1. The charging or suction stroke, when the gas and air are drawn in.

2. The compression, during which the charge is compressed.

3. The explosion or power stroke at the beginning of which the explosion takes place.

4. The exhaust or scavenging stroke, during which the burnt gases are forced out.

That is known as the "Beau do Rochas," or sometimes as the "Otto" cycle, names derived from the early experimenters in gas-engine work.

Now it will be noted that power is only developed in one stroke out of four. The other three strokes consume power instead of giving it out. So the fly-wheel has to be very heavy in order that its momentum may do all the work needed during the three idle strokes.

But there are few engines nowadays with only one cylinder. Most of them have several, but they all turn the same crankshaft. Each has its own crank, however, and they are so arranged that the explosions occur in succession and not all at once. Thus the turning effect of them all together is fairly even, and not so jerky as one cylinder alone would be. It is this use of a number of cylinders which accounts to a large extent for the small vibration of a modern car compared with the older ones.

Another great improvement which has taken place is in the valves, which let the charge into the cylinder and the waste gases out. These used to make a clatter as they opened and closed; hence at one time horns were hardly needed by motor vehicles. Improved methods of construction have now resulted in their working so silently that the modern high-class car steals along almost without a sound.

Motor-car engines of all kinds work at a high speed, since by that means their weight is reduced. For it is clear that a small engine working fast can exert as much power as a large one working slowly.

The highest speed, in fact, is much faster than that needed for the wheels unless going very fast. There is therefore a series of tooth-wheels between the engine and the wheels which can be brought into operation in various combinations, so that the engine while running at a constant speed could impart various speeds to the wheels.

As a matter of fact, however, the speed of the engine is by no means constant. Within easy reach of him the driver has either a pedal or a small handle by which he can regulate the proportion of gas (petrol vapour) in the charge. The more there is the more powerful are the explosions and the faster the speed. On the other hand, a reduction of the gas means a slower speed.

The change-speed gears are used mostly for climbing hills, when the engine can be run fast, so as to generate its greatest power, while the car runs slowly. For variations in speed in the ordinary way the pedal or handle is used, hence it is called the "Accelerator."

Another important part of the mechanism is the Differential Gear, an arrangement of tooth-wheels which permits both back wheels to be driven round by the engine, yet leaves them independent to the extent that going round corners one may turn faster than the other.

But while strongly entrenched, the petrol motor is not without its rivals. There are some very beautiful steam cars on the road. They mostly work with boilers of what are called the "flash" type. This means that the boiler is normally empty, but when steam is needed a little water is sprayed in with a pump. The boiler being hot, it instantly flashes into steam, hence its name. The speed of the engine can be varied by altering the amount of water sprayed in.

One great advantage of the steam-engine is the ease with which it starts and stops. Heat up the boiler, inject some water, and away it goes. The petrol motor, because of its idle strokes, has to be "wound up" as it were, for it is quite evident that until it has gone through a suction stroke and a compression stroke a power stroke is impossible.

A steam-engine can stop and then at once restart in the reverse direction with but a slight alteration in its valves, accomplished by the mere movement of a handle, while the petrol engine can only go one way, and reversing has to be done by means of certain wheels in the gear-box.

Electricity, too, has great advantages, but they are at present outweighed in all but a few instances by the weight and the wastefulness of the accumulators which have to be carried to supply the current. In addition to which there is the time during which the car is laid up, either changing the discharged accumulators for charged ones, or worse still, recharging them while on the car, for the latter is a slow process.

A famous inventor has been for a long while promising us a new type of light accumulator, but so far he has not kept his word, and it rather looks as if he had met his match in this problem. Until someone does that there is not much chance for the electric vehicle, other than, of course, the tramcar, which can pick up its current *en route.*

But strange to say the petrol motor and the electric motor do well in partnership, particularly for heavy vehicles, such as large buses. One of the troubles with them is the banging and clanking which takes place when the gear wheels are manipulated. With lighter cars it does not matter so much, but with heavy ones the power transmitted through the gearing is so great, and the gears themselves are so large and heavy, that their operation is heavy and clumsy, and the wear and tear is heavy too.

But an electric motor is one of the most adaptable of machines. It will as leave go one way as the other ; it starts itself when required, it will vary its speed within very wide limits—in fact, it is really just the thing for driving a road vehicle, for it is as easy to control as a well-trained horse. On the other hand, a dynamo likes to be driven at a constant high speed, the very condition under which a petrol motor is at its best. So let the petrol engine drive a little dynamo, and let the current from that drive two small motors, one fixed to each of the back wheels, and you have a splendid combination. The starting and stopping and the variations in speed are then all done electrically, no gearing is needed, reversing is quite easy; the petrol engine is started once and then goes on its own sweet way with little oversight from the driver. Such an arrangement is rather heavy, because of the weight of the dynamo and motors, but it has many advantages. Not only road locomotives use it, but motor coaches on railways. Indeed ships are now being driven by the same method, current being generated by a constant high-speed turbine or gas-engine and dynamo, and working (at a moderate and variable speed) the motor connected to the propeller.

One source of trouble in the petrol engine is the ignition of the gas just at the right moment. This is always done by an electric spark, derived generally from an induction coil, which draws its exciting current from either an accumulator or a primary battery.

There is a new type of engine now coming into prominence, the Diesel engine, which needs neither ignition nor carburettor, the necessary heat to ignite the fuel being obtained by making the compression very high and the fuel being used in its liquid state. Pure air is drawn in during the suction stroke, and the compression which follows in the next stroke is so great that the air becomes, because of it, hot enough to ignite a spray of oil which is at the right moment injected into the cylinder. This may or may not be the car-motor of the future.

HIGH-SPEED RAILWAYS

A CENTURY ago a long journey was considered an exploit, and an exploit to be carried through as quickly as possible on account of the dangers of the road and the generally uncomfortable conditions of travel. To-day, though our express speed is many times greater than that of the lumbering coaches, our carriages comparatively luxurious, the risk practically nil, the same wish lurks in the breast of ninety-nine out of a hundred railway passengers—to spend the shortest time in the train that the time-table permits of. Time differences that to our grandfathers would have appeared trifling are now matters of sufficient importance to make rival railway companies anxious to clip a few minutes off a 100-mile "run" simply because their passengers appreciate a few minutes' less confinement to the cars.

During the last fifty years the highest express speeds have not materially altered. The Great Western Company in its early days ran trains from Paddington to Slough, 18 miles, in 15½ minutes, or at an average pace of 69½ miles an hour.

On turning to the present regular express services we shall find that the speed is not now improved upon to any great extent anywhere. Indeed, the particular run referred to (London to Slough) now takes longer than it used to do. Speeds of ninety or even more miles per hour are sometimes attained for short distances, but the average, even on the best lines, is much lower than that, for long distances.

This is largely due to the limits which are imposed by the tracks, for constant high speeds would entail great wear and tear on the line itself, wearing the rails and sleepers, loosening the chairs and the keys which hold the rails in them, and also loosening the sleepers in their beds of ballast. This would need constant renewals and attention, all of which means added cost for which the public are not prepared to pay.

It is doubtful too whether the public really want such very high speeds. Some of the best railways have so mastered the art of building carriages that little vibration is felt whatever be the speed, and if lines were all quite straight people would probably not mind being whizzed along at 100 miles an hour, but the lines are not by any means straight, and consequently high speed means constant swaying to and fro from side to side, an experience which is not by any means pleasant. Indeed, the curves are a positive danger at high speeds, as was shown by the terrible accident at Salisbury some years ago, in which a boat train from Plymouth, carrying the passengers from an Atlantic liner to London, rushed round a curve at too high a speed, with the result that the engine actually capsized.

The swaying which affects passengers at every curve always suggests this possibility to people who are the least nervous, and so it is safe to say that, with the present form of track at any rate, higher speeds will never come into use.

Various people have suggested new forms of railway track in which high speeds would be possible without these dangerous or nerve-racking swayings, but although some experimental lines of short length have been built, nothing has ever come of them.

But another and perfectly satisfactory way of increasing the average speed of a journey has been applied to many short busy lines, like those in the suburbs of large cities. Suppose that a train runs a journey of 20 miles with a stop at every mile, taking 60 minutes to do it. The speed will then average, including stops, 20 miles an hour. If after each stop it can get up full speed more quickly than it used to do, thereby saving half a minute at each, it will save 10 minutes on the whole journey. The average speed will then jump up to 24 miles an hour. If one minute can be saved on each stop, then the average will rise to 30 miles an hour, or half as fast again as the old speed.

Now, our faithful old friend, the steam locomotive, is bad at starting. Its cylinders get cold while it is standing, and the first steam which enters it becomes condensed and loses power. It takes a little while to get over this trouble, and so a steam-driven train starts slowly. An electric motor, on the other hand, is at its best when starting. It can exert its greatest power in an instant. For a few moments it can pull 50 per cent. harder than it would be safe to allow it to do for any length of time. Consequently an electric train can get up speed much more quickly than a steam one can.

And not only does this save time on the whole journey, resulting, as we have seen, in a much improved average speed, but it greatly improves the earning capacity of the line, a matter of much concern to directors. A train standing in a station or slowly gathering way as it leaves it may be blocking another train just behind. The sooner the first one gets clear away the sooner will the second be able to follow it into the station. Thus by electric traction it is often possible to increase very greatly the number of trains per hour.

And a further advantage of electric traction on short busy lines is that it is cheaper. The familiar puffing of the steam locomotive is but so much energy being blown to waste. The force which shoots the steam up the chimney ought to be employed in pulling the train. Listen outside an electric generating station and you will hear no puffing. *There* the steam is made better use of. Not only is it used over and over again until all its force, practically, has gone, but it passes from the engine into a cold chamber, the condenser, where, being cooled, it collapses into water and forms a vacuum, the suction of which is added to the driving force of the steam. As the steam pushes at one side of the engine-piston the vacuum pulls at the other.

Watch a steam locomotive, too, on a dark night, and notice the sparks which it blows into the air. Those sparks are half-burned fuel. They ought to be kept inside the boiler-furnace until they had given up all their heat. There is no such waste in the generating station.

In short, the steam-engine and boiler, when used to generate electricity, can be put under the best possible conditions. Every device known to man for saving coal and making the best use of the steam can be employed there. But the same cannot be done on the locomotive, for the simple reason that the latter has to run on two rails less than five feet apart, and must not be too long to go comfortably round the sharpest curves. Within these limitations steam locomotives are splendid engines, but they can never compare well with their more fortunate comrades comfortably ensconced in spacious engine-houses with all the latest accessories to help them.

So to sum up, you can turn coal into power more economically in a stationary plant than in one on wheels. And electricity affords a convenient means of taking that power from the stationary engine to a moving train.

The engines drive dynamos, thereby generating current: this passes along conductors to the trains: there it goes to the motors which change it back into power, which turns the wheels and so drives the trains along. Thus an electric installation on a railway consists of three parts:

The generating plant.

The conductors which distribute the current.

The motors on the trains.

There are two principal types of electric railway. One is known as the "direct-current" system, and the other as the "single-phase" system.

The underground railways of London are all examples of the former, and so are the Lancashire and Yorkshire Company's electric lines in the neighbourhood of Liverpool. All tramway or "street-railway" systems are direct-current too. On the other hand, the electric railways in the south of London and the Midland Company's electric line in Lancashire are single-phase.

The chief difference between the two seems at first sight to be ridiculously trifling; it is simply that in one case the current flows one way in a steady stream, while in the other it flows to and fro at short intervals. Yet that seemingly slight difference entails the use of quite different plant.

Now to commence with, one must understand that there are two things to be thought of in connection with a current of electricity—its force and its volume. We may liken it to water in a pipe; 100 gallons a minute at a pressure of 100 pounds per square inch will do no more work than 50 gallons at 200 pounds pressure. But a pipe half the size will suffice to carry the latter.

Now let us carry the same principle to electricity. A current of, say, 100 amperes (which is the measure of volume, just as gallons per hour is in the case of water), at a force or pressure of 500 volts, will do a certain amount of work, which is denoted by 50,000 watts, the measure of the *work* which a current is capable of doing. The number of watts, as will be seen, is obtained by multiplying the number of amperes and the number of volts together, and so it is evident that 10 amperes at 5000 volts would do just as well. And 10 amperes will need a much smaller conductor than 100 will. And, further, conductor wires have to be of copper, which is very expensive. Moreover, less of the energy is lost in the latter case through its fight against the "friction," or resistance of the wire. Consequently when current has to be sent in any quantity over any considerable distance it is necessary for economy's sake that it be at a high voltage. But then the difficulty crops up that the kind of dynamo which generates direct current does not work well at a high voltage. So there is nothing for it, if direct current be needed, but to generate alternating current, and then convert it into direct current later on. So the dynamos generate high-voltage alternating current—current, that is, which surges to and fro many times per second.

The current which drives the London Underground Railways leaves the great generating station at Chelsea at a pressure of 11,000 volts. But that is far too high for use in the motors, and, moreover, they want direct current. Dotted about, therefore, at different parts of the railway system there are sub-stations at which this current is changed. It goes from Chelsea to the sub-stations, not along the conductor rails, but through cables, and on its arrival it goes first of all to transformers, gigantic induction coils really, in which it is converted from *a little* current at 11,000 volts into *a lot* of current at about 500 volts. Thence it goes to machines called converters, which change it from alternating current into direct current. From them it at last passes to the "positive" rail. This is a steel rail laid at one side of the track outside the track rails. It is supported on insulators of earthenware, and the trains having iron shoes which slide along it pick up the current from it as they move.

Having worked the motors on the train the current goes through the "negative" shoes to the "negative" rail, which is placed upon insulators in the centre between the track rails. These guide it back to the sub-station.

So on lines worked in this way the current has quite an eventful time. It leaves the generating station small but strong; arriving at the transformer it grows in volume mightily, but loses correspondingly in force. Next in the converter its character is changed, and then only is it ready to do its work. Having done it, it trickles back exhausted, and with practically all its force spent, to the place whence it started.

Now all that trouble and expense is endured in order to obtain the benefit of the many virtues of the direct-current motor. It is a beautiful machine, as docile and well under control as a perfectly trained horse, as powerful as many horses, equally ready to go forwards or backwards, springing to its work with the first movement of the controller handle, and putting forth its best efforts just when most needed, and strictly economical withal, for it absolutely refuses to consume more current than just enough to do its work. It is worth a good deal to be able to use such a good machine as that.

But of recent years another motor—a very near relative of the direct-current motor—has come upon the scene. It is not quite so good, perhaps, although it is very nearly so; and it will work with alternating current. Its name is the "Single-phase Railway Motor."

Why it has this name needs a little explanation. Dynamos which generate alternating current are often so wound with wire that they generate two, three, or even more *separate* currents, which flow out along a corresponding number of separate wires. These are all just the same, except that they vary in "phase." That is to say, one current begins to flow one way in the first, gradually grows in force, then as gradually fades away and commences to flow the other way. So it goes on, first one way and then the other. The next current does just the same, only *a moment later*. The third current, if there be one, follows *a moment later* still. Thus the waves of current, as we might call them, flow along parallel wires *in succession*. This difference in time constitutes the different phases. When there are three currents like this they are spoken of collectively as three-phase current. When there are two they are called two-phase current. And when there is only one it is spoken of as single-phase current.

Now this single-phase current at a great pressure, thousands of volts, is led direct to an overhead conductor, consisting of a copper wire suspended from beams or arms which span the track at intervals. On the tops of the trains there are collectors which touch the overhead wire as the train passes along, and through which the current passes. But even the single-phase motor cannot digest current at thousands of volts, so every train has to carry its own transformer, to which the current goes first of all. Having been transformed down to a moderate voltage it goes to the motors, from them passing to the rails on which the train runs, finding its way home through them to the generating station.

By this means the cost of the sub-stations is avoided, for the need of the converters vanishes altogether, and so far as the transformers are concerned each train becomes its own sub-station.

On the other hand, the cost of the overhead conductor, with the elaborate structures to support it, is much greater than that of a mere steel rail laid on the ordinary sleepers. The single-phase motors, too, are heavier than direct-current motors of equal power, and that extra weight, with the weight of the transformers added to it, has got to be hauled about wherever the train goes. So there is much discussion as to the merits of these rival systems, and which is the cheapest and best the writer would not like to say.

If ever we go in for either of them for the long trunk lines of the country we may have to face the question and decide on one or the other, for unless we do that we shall find ourselves, as we did in the old days when some lines were broad gauge and others narrow, unable to run through trains from one system to another. At any rate, a change of engines would be necessary to get over the difficulty, but when we use electricity for driving our trains we like to get rid of engines altogether and put the motors on one or two coaches in each train. We not only save weight by that means, but we do away with the bother of shunting the engines about. At large terminal stations, particularly, engines which pull trains in are often imprisoned for hours. Other engines have to pull the trains out again, and the first have then to be shunted on to other trains. Often when passengers are puzzled because a train does not start to time it is because, owing to some little disorder, the engine which is to take them is bottled up somewhere and cannot get to its train. One of the advantages of electric traction is that all that bother is avoided, but if separate engines are employed it is as bad as ever.

It is true that in the United States there is at least one route along which trains travel under both systems. For the single-phase motors will work with direct current, and so if they be fitted with the proper shoes as well as the overhead collector, they can operate on lines fitted for direct current as well as those intended for single-phase trains. But although they can thus run on the direct-current lines, they cannot do so as economically as properly constructed direct-current trains can.

But probably we shall stick for many years to come yet to the old "puffer" for our long-distance trains. The advantages of the electric train, as we have seen, are greatest on suburban lines—on short distances, that is, with many stoppages. On those lines, too, the disadvantage of electricity, namely, the great first cost of the installation, is at its smallest. On long distances with but few stops the steam-engine makes a better show, and the cost of electrifying long lines would be something enormous.

But perhaps electricity will have its share in the long-distance work in another way. Think of a steam turbine mounted on wheels with a boiler attached, and with all the auxiliaries which go to make the generating station so much more economical than the ordinary steam locomotive. Such an engine is already in existence. But the turbine works much too fast to be connected directly to the wheels, so it works a dynamo, which in turn drives electric motors which turn the wheels. Thus the locomotive becomes a travelling generating station, and we see steam traction and electric traction combined in the same machine.

SEA EXPRESSES.

In the year 1836 the *Sirius*, a paddle-wheel vessel, crossed the Atlantic from Cork Harbour to New York in nineteen days. Contrast with the first steam-passage from the Old World to the New a journey in any of the present Atlantic fliers, which do the trip under five days. The passing to and fro of ships has been spoken of as the movement of the "shuttles of trade" weaving a fabric of international commerce, and certainly the Atlantic steamers are like shuttles in the swiftness and directness with which they dart from one side of the broad ocean to the other.

This growth of speed is even more remarkable than might appear from the mere comparison of figures. A body moving through water is so retarded by the inertia and friction of the fluid that to quicken its pace a force quite out of proportion to the increase of velocity must be exerted. The proportion cannot be reduced to an exact formula, but under certain conditions the speed and the power required advance in the ratio of their cubes; that is, to double a given rate of progress eight times the driving-power is needed; to treble it, twenty-seven times.

The mechanism of our fast modern vessels is in every way as superior to that which moved the *Sirius*, as the beautifully-adjusted safety cycle is to the clumsy "boneshaker" which passed for a wonder among our grandfathers. A great improvement has also taken place in the art of building ships on lines calculated to offer least resistance to the water, and at the same time afford a good carrying capacity. The big liner, with its knife-edged bow and tapering hull, is by its shape alone eloquent of the high speed which has earned it the title of Ocean Greyhound; and as for the fastest craft of all, torpedo-destroyers, their designers seem to have kept in mind Euclid's definition of a line-length without breadth. But whatever its shape, boat or ship may not shake itself free of Nature's laws. Her restraining hand lies heavy upon it. A single man paddles his weight-carrying dinghy along easily at four miles an hour; eight men in the pink of condition, after arduous training, cannot urge their light, slender, racing shell more than twelve miles in the same time.

To understand how mail boats and "destroyers" attain, despite the enormous resistance of water, velocities that would shame many a train-service, we have only to visit the stokeholds and engine-rooms of our sea expresses and note the many devices of marine engineers by which fuel is converted into speed.

We enter the stokehold through air-locks, closing one door before we can open the other, and find ourselves among sweating, grimy men, stripped to the waist. As though life itself depended upon it they shovel coal into the rapacious maws of furnaces glowing with a dazzling glare under the "forced-draught" sent down into the hold by the fans whirling overhead. The ignited furnace gases on their way to the outer air surrender a portion of their heat to the water from which they are separated by a skin of steel. Two kinds of marine boiler are used—the fire-tube and the water-tube. In fire-tube boilers the fire passes inside the tubes and the water outside ; in water-tube boilers the reverse is the case, the crown and sides of the furnace being composed of sheaves of small parallel pipes through which water circulates. The latter type, as generating steam very quickly, and being able to bear very high pressures, is most often found in war vessels of all kinds. The quality sought in boiler construction is that the heating surface should be very large in proportion to the quantity of water to be heated. Special coal, anthracite or Welsh, is used in the navy on account of its great heating power and freedom from smoke ; experiments have also been made with crude petroleum, or liquid fuel, which can be more quickly put on board than coal, requires the services of fewer stokers, and may be stored in odd corners unavailable as coal bunkers.

From the boiler the steam passes to the engine-room, whither we will follow it. We are now in a bewildering maze of clanking, whirling machinery; our noses offended by the reek of oil, our ears deafened by the uproar of the moving metal, our eyes wearied by the efforts to follow the motions of the cranks and rods.

On either side of us is ranged a series of three or perhaps even four cylinders, of increasing size. The smallest, known as the high-pressure cylinder, receives steam direct from the boiler. It takes in through a slide-valve a supply for a stroke; its piston is driven from end to end; the piston-rod flies through the cylinder-end and transmits a rotary motion to a crank by means of a connecting-rod. The half-expanded steam is then ejected, not into the air as would happen on a locomotive, but into the next cylinder, which has a larger piston to compensate the reduction of pressure. Number two served, the steam does duty a third time in number three, and perhaps yet a fourth time before it reaches the condensers, where its sudden conversion into water by cold produces a vacuum suction in the last cylinder of the series. The secret of a marine engine's strength and economy lies then in its treatment of the steam, which, like clothes in a numerous family, is not thought to have served its purpose till it has been used over and over again.

Reciprocating (*i.e.* cylinder) engines, though brought to a high pitch of efficiency, have grave disadvantages, the greatest among which is the annoyance caused by their intense vibration to all persons in the vessel. A revolving body that is not exactly balanced runs unequally, and transmits a tremor to anything with which it may be in contact. Turn a cycle upside down and revolve the driving-wheel rapidly by means of the pedal. The whole machine soon begins to tremble violently, and dance up and down on the saddle springs, because one part of the wheel is heavier than the rest, the mere weight of the air-valve being sufficient to disturb the balance. Now consider what happens in the engine-room of high-powered vessels. On destroyers the screws make 400 revolutions a minute. That is to say, all the momentum of the pistons, cranks, rods, and valves (weighing tons), has to be arrested thirteen or fourteen times every second. However well the moving parts may be balanced, the vibration is felt from stem to stern of the vessel. Even on luxuriously-appointed liners, with engines running at a far slower speed, the throbbing of the screw (*i.e.* engines) is only too noticeable and productive of discomfort.

We shall be told, perhaps, that vibration is a necessary consequence of speed. This is true enough of all vehicles, such as railway trains, motor-cars, cycles, which are shaken by the irregularities of the unyielding surface over which they run, but does not apply universally to ships and boats. A sail or oar-propelled craft may be entirely free from vibration, whatever its speed, as the motions arising from water are usually slow and deliberate. In fact, water in its calmer moods is an ideal medium to travel on, and the trouble begins only with the introduction of steam as motive force.

But even steam may be robbed of its power to annoy us. The steam-turbine has arrived. It works a screw propeller as smoothly as a dynamo, and at a speed that no cylinder engine could maintain for a minute without shaking itself to pieces.

The steam-turbine is most closely connected with the name of the Hon. Charles Parsons, son of Lord Rosse, the famous astronomer. He was the first to show, in his speedy little *Turbinia*, the possibilities of the turbine when applied to steam navigation. The results have been such as to attract the attention of the whole shipbuilding world.

The principle of the turbine is seen in the ordinary windmill. To an axle revolving in a stationary bearing are attached vanes which oppose a current of air, water, or steam, at an angle to its course, and by it are moved sideways through a circular path. Mr. Parsons' turbine has of course been specially adapted for the action of steam. It consists of a cylindrical, air-tight chest, inside which rotates a drum, fitted round its circumference with rows of curved vanes. The chest itself has fixed immovably to its inner side a corresponding number of vane rings, alternating with those on the drum, and so arranged as to deflect the steam on to the latter at the most efficient angle. The diameter of the chest and drum is not constant, but increases towards the exhaust end, in order to give the expanding and weakening steam a larger leverage as it proceeds.

The steam entering the chest from the boiler at a pressure of some hundreds of pounds to the square inch strikes the first set of vanes on the drum, passes them and meets the first set of chest-vanes, is turned from its course on to the second set of drum-vanes, and so on to the other end of the chest. Its power arises entirely from its expansive velocity, which, rather than turn a number of sharp corners, will, if possible, compel the obstruction to move out of its way. If that obstruction be from any cause difficult to stir, the steam must pass round it until its pressure overcomes the inertia. Consequently the turbine differs from the cylinder engine in this respect, that steam *can* pass through and be wasted without doing any work at all, whereas, unless the gear of a cylinder moves, and power is exerted, all steam ways are closed, and there is no waste. In practice, therefore, it is found that a turbine is most effective when running at high speed.

The first steam-turbines were used to drive dynamos. In 1884 Mr. Parsons made a turbine in which fifteen wheels of increasing size moved at the astonishing rate of 300 revolutions per second, and developed 10 horse-power. In 1888 followed a 120 horse-power turbine, and in 1892 one of 2000 horse-power, provided with a condenser to produce suction. So successful were these steam fans for electrical work, pumping water and ventilating mines, that Mr. Parsons determined to test them as a means of propelling ships. A small vessel 100 feet long and 9 feet in beam was fitted with three turbines—high, medium, and low pressure, of a total 2000 horse-power—a proportion of motive force to tonnage hitherto not approached. Yet when tried over the test course the *Turbinia*, as the boat was fitly named, ran in a most disappointing fashion. The screws revolved *too fast*, producing what is known as *cavitation*, or the scooping out of the water by the screws, so that they moved in a partial vacuum and utilised only a fraction of their force, from lack of anything to "bite" on. This defect was remedied by employing screws of coarser pitch and larger blade area, three of which were attached to each of the three propeller shafts. On a second trial the *Turbinia* attained 32¾ knots over the "measured mile," and later the astonishing speed of forty miles an hour, or double that of the fast Channel packets. At the Spithead Review in 1897 one of the most interesting sights was the little nimble *Turbinia* rushing up and down the rows of majestic warships at the rate of an express train.

After this success Mr. Parsons erected works at

Wallsend-on-Tyne for the special manufacture of turbines. The Admiralty have now practically given up the reciprocating engine, all modern warships of any size or speed having steam turbines.

By their aid some of the Destroyers do over 40 miles an hour, one at least having been known to exceed 44 miles. Even heavily armoured "Dreadnought-cruisers" can speed through the sea at 34, 35, or even 36 miles an hour.

For merchant ships, except the very fast liners, the turbine is too fast. We have already referred to the fact that a screw propeller if driven beyond a certain speed loses its grip upon the water, and unless the boat be a very fast one the highest permissible speed for the propeller is much below the lowest economical speed of the turbine. Ships are being built in which large tooth gearing is being used to reduce the speed of the turbines to that of the propellers. Electricity has been proposed, too, for the same purpose, each turbine to drive a dynamo, which in turn will drive motors attached to the shafts of the screws.

This overcomes another trouble with the turbine—it will not reverse. In turbine ships there have to be two sets of turbines, some for going ahead and others, with the vanes set the opposite way, for going astern. Whichever set are in use the others revolve idly. In warships, too, which have to use two distinct speeds, one for going fast and the other for cruising—strolling about, as it were—

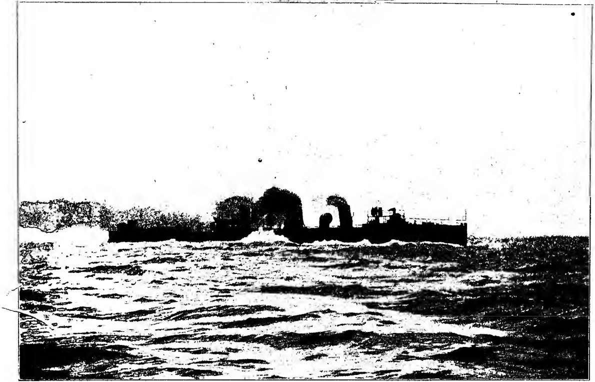
there have to be special cruising turbines, for the fast-speed turbines would be terribly wasteful if used for the slower speed.

The great advantage of the turbine apart from the reduced vibration is that it uses practically all the force in the steam, which the reciprocating engine never does quite. Indeed, the turbine is at its best with steam which the reciprocating engine has done with. Some ships, therefore, notably the *Olympic* and its ill-fated sister the *Titanic*, have been fitted with reciprocating engines which take steam direct from the boilers, and turbines which take the steam from them after they have used it.

But young though the steam turbine is, it already has a rival coming to the front in the Diesel oil engine. The invention of Dr. Diesel, of Munich, this wonderful machine works with crude cheap oil, needs no boilers, seems to be very reliable and manageable, can be made to work at suitable speeds, and can be readily reversed. It has not yet been made in sizes any way approaching that of the large turbines, but that will probably come in time. Or the electric method of driving may come in in connection with it. Utilising the space saved through the absence of boilers and coal-bunkers, a large number of these, directly coupled to dynamos, might be installed upon a ship, generating current to drive four, or even five or six propellers, each having its own electric motor. Such a ship might have a speed altogether undreamed of now, and for handiness it would beat anything afloat, for the officer in command would have a row of handles on the bridge, one for each propeller, and he would drive the ship by them, just as the motor-man drives an electric tramcar. No telegraphing of orders to the engine-room would be necessary, but instead each propeller would be directly under control from the bridge. The oil-fuel being stowed away in the double bottom now devoted to water-ballast would be pumped up as required. The army of toilers down below in the boiler rooms and the coal-bunkers would be quite unnecessary, and the engines themselves would run almost unattended.

Altogether this new motor opens up the most alluring possibilities for the future, not only in the way of speed, but in comfort for the passengers. For the best parts of the ships at present are taken up by the funnels and the necessary openings over the boiler rooms. With the oil engines there would be no funnels, and the engine-rooms could be ventilated in other ways. And greatest point of all to the sympathetic man, the passenger on the sea express could take his fast trip without feeling that he was purchasing it at the expense of the poor fellows down below, toiling at almost inhuman toil feeding those greedy fires, in a perfect inferno, and exposed in the event of disaster, as the *Titanic* showed, to almost certain death.

The sea express has great developments in promise in the near future.



H.M.S. Torpedo Destroyer "Viper." —This vessel was the fastest afloat, attaining the enormous speed of 41 miles an hour. The screws were worked by turbines, giving 11,000 horse-power. She was wrecked on Alderney during the Naval Manœuvres of 1901.

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MECHANICAL FLIGHT.

FEW, if any, problems have so strongly influenced the imagination and exercised the ingenuity of mankind as that of aërial navigation. There is something in our nature that rebels against being condemned to the condition of "featherless bipeds" when birds, bats, and even minute insects have the whole realm of air and the wide heavens open to them. Who has not, like Solomon, pondered upon "the way of a bird in the air" with feelings of envy and regret that he is chained to earth by his gross body; contrasting our laboured movements from point to point of the earth's surface with the easy gliding of the feathered traveller? The unrealised wish has found expression in legends of Dædalus, Pegasus, in the "flying carpet" of the fairy tale, and in the pages of Jules Verne, in which last the adventurous Robur on his "Clipper of the Clouds" anticipates the future in a most startling fashion.

It was many years after the invention of the steam-engine that it was found possible to equip a balloon with mechanical power. The year 1852 witnessed the first attempt to do this, the experimenter being Henry Giffard, who built in Paris a spindle-shaped balloon, the length of which was 130 feet. The car was furnished with two-winged propellers and a three horse-power steam-engine. By its own power in still air this airship had a speed of four miles per hour. Long before Giffard's time an egg-shaped balloon had been projected by General Meusnier. It was to be fitted with hand-worked propellers and a rudder. But the idea was anticipated by the brothers Robert in 1784, who achieved a small measure of success.

Throughout the early part of the nineteenth century various attempts were made to obtain dirigibility by hand-propelled machines, some with screw-propellers, others with oars. But Henry Giffard is the "father" of the modern dirigible balloon. From the earliest attempts to the beginning of the twentieth century very little progress was made. The Renard airship of 1884 was almost as good as the airship of twenty years later, except for the motive-power. By the year 1905, however, the dirigible balloon had indeed become established. The Zeppelin, the Parseval, the Lebaudy, the Baldwin, and the Gross, even the dilatory British military dirigible, crowded on each other, and airship factories sprang up.

The problems before the dirigible balloon concern strength, stability, and equilibrium. Powerful engines can be taken up—that is only a question of lifting power, the size of the balloon; but if the balloon is driven against the air beyond a certain speed it will not bear the strain.

One of the most famous airships of the rigid type was Zeppelin No. 4, which was destroyed when making a twenty-four hours' trip down the Rhine. In size it was six or eight times that of the first British airship, being 426 feet long and 42 feet in diameter, and having a capacity of 455,000 cubic feet. It had a rigid aluminium framework, containing seventeen ballonets, or separate compartments filled with hydrogen. It had an aluminium keel, and a sliding weight to preserve the balance of the vessel. It was fitted with two cars and four three-bladed propellers, and planes for steering.

It is claimed by some that the rigid principle has been triumphantly indicated by Zeppelin's airships, but Surcouf, the famous French aeronaut, declares that the rigid metallic frame is an absurdity, and that no progress will ever be made in this direction. Indeed he, like Maxim, predicted the destruction of Zeppelin's airship on the day before the trial.

The non-rigid type adheres to the ordinary envelope, inflated to such an extent as to be almost rigid, or provided with special appliances preventing flabbiness. The non-rigid balloon cannot, of course, avoid at times suffering reduction of bulk through passing into low temperatures and from other causes, and when flabby the wind has too much power over it.

Hydrogen gas is, moreover, extremely volatile, and it will percolate through almost any substance. The first British airship was of this type. This balloon, which was wrecked during a trial trip, measured 120 feet long and 25 feet in diameter, and was driven by an eight-cylinder 50 horse-power motor. There were two propellers, driving the vessel at something like 20 miles an hour in still air.

In order to have a gas-container that would be more or less proof against the filtration of the gas through the fabric, combined with strength sufficient to allow of tightness in inflation, the British War Office went to the expense of making a gold-beater's skin envelope of special quality and character. Its cost was not less than £2000. Naturally it was not made of one layer of skin only, but consisted of about fifteen layers. To provide the skin for this envelope, it is reckoned that no fewer than 200,000 oxen must have contributed. The joining together of all the small pieces entailed a prodigious amount of labour. Between the layers of skin a certain amount of silk thread was used. This item alone cost £30. And it is doubtful, even if that particular type of airship had proved itself at all comparable in point of efficiency with the French and German aerial warships, whether it could have been made in sufficient numbers for practical purposes.

Various methods have been devised for taking tucks in the envelope when it becomes flabby, or for refilling the bag from a supply of gas carried in small containers with the balloon; but while many of these devices are better than nothing at all, not one of them is quite satisfactory.

General Meusnier, in 1784, offered one solution of this difficulty, suggesting a gas-envelope surrounded by a space for compressed air, enclosed in an outer envelope. When the space between the two envelopes is filled with air, the weight of the air would be so much added to the burden of the balloon, reducing its lift. It would also compress the gas-envelope, condensing the gas, and thereby further checking the lifting power. In order to obtain ascensive power, the aeronaut would simply have to pump air out of the air-cover and allow the gas balloon to extend.

The ballonet now in general use is an air-pocket contained within the gas-envelope.

A compromise between the rigid and non-rigid type is the Lebaudy—a form of airship which is held by many experts to be superior to the Zeppelin. In this the gas-envelope rests in a keel or bed of metal tubing. In 1902 the Lebaudy brothers made one of this kind in which the strain was taken off the gas-envelope, and the structure was much better knit together and more stable than any of its predecessors. It was by far the best airship that had been produced, and the type was speedily adopted by the French army. Another non-rigid airship is the *Ville de Bordeaux*, built by Surcouf; it is one of the noteworthy series *Ville de Paris*, *Clement-Bayard*, and others. The gas-envelope of the first of these was 170 feet long and 47 feet in diameter, and held about 100,000 cubic feet of gas, in addition to an air-ballonet, which maintained the pressure under varying conditions. The engine was an 80 horse-power four-cylinder Renault. In front of the car was a triplane elevator, having a surface of 560 square feet, and behind was a double rudder for steering. Stability was to some extent provided for by a group of four pear-shaped gas-bags surrounding the rear end of the main envelope. The car was 90 feet long. The envelope was of rubber fabric. Its maximum diameter was well forward.

In spite of all difficulties, dirigible balloons capable of an independent speed of 20 to 26 miles per hour have been made in considerable numbers of late years. In the air they are, if properly made, perfectly safe. Their principal danger is in descending to the ground in a high wind. Then their enormous area offers great resistance to the wind, and they are very apt to be "buckled," and even to be hurled over and destroyed by gusts. With these limitations the dirigible balloon is nevertheless a machine of great possible utility. There are many days in the year when it is valueless, but that fact will not prevent its use becoming so general that special harbours will ere long have to be provided. These harbours might be excavated, or they might be huge edifices in which an airship could find security from the storm.

In the construction of the dirigible balloon great care must be taken to build the framework strong as well as light, so to suspend the car from it that the weight is equally distributed, and, above all, so to contrive the gas-container that under no circumstances can it become tilted. There is great danger in the case of tilting that some of the stays suspending the car may snap, and that the huge airship will, in fact, fall to pieces in the air. During flight pitching is unavoidable. It is due to irregularity in the velocity of the wind, to ascending and descending air-currents, to the irregular driving action of the motor, and, in the case of the Zeppelin balloon, to the unequal loss of gas in different cells. In the distribution of weight regard must be paid to the distribution of the lifting force. For movements to one side, equilibrium may be maintained by a movable weight or by a horizontal rudder. These are the more obvious considerations. There are innumerable minor points which concern the builder and navigator.

In deciding upon the shape of a dirigible balloon, the chief consideration is to secure an end-surface which presents the least possible resistance to the air, and also to secure stability and equilibrium; various eccentric shapes have been evolved. The question of motor, fuel, and propellers are, of course, of vital importance, and in all directions there is constant development and continual straining for the attainment of perfection.

Dirigible balloons do not ascend to such great altitudes as do spherical balloons. Seldom indeed do they ascend higher than 4000 or 4500 feet. Great altitudes can only be attained by the sacrifice of ballast or by permitting great expansion and consequent waste of gas. The necessity to keep the gas in a dirigible balloon as equable as possible makes high ascents undesirable.

A combination of airship and aeroplane has been devised by M. Malécot, but in some respects his work was anticipated by Barton in England and by many earlier designers. The Malécot airship consists of a spindle-shaped gas-envelope, 100 feet long, 24 feet in diameter, and of a capacity of 36,900 cubic feet. Suspended beneath it by a number of ropes is an aeroplane 63 feet in length. The planes are inclined at a sharper upward angle than is usual in aeroplanes. The 30 horse-power motor is fitted into a sort of cage, where there is also sufficient room for a pilot and a mechanic. The propeller consists of a single piece of wood strengthened with metal, and measures about 11 feet in diameter. Below the aeroplane there is a basket which can carry a weight of 600 pounds, which helps both to give the airship greater stability and to adjust the aeroplane at different inclinations as required. The balloon is provided with a ballonet.

In making an ascent the aeronaut adjusts the aeroplane, so that when the motor is started and the propellers revolve the planes have a forward, upward, gliding motion. The advantage of a mixed airship of this description is supposed to consist in the fact that less gas is needed to inflate the balloon, and that in case an accident should occur, the aeroplane would be able to continue its flight alone for some distance, or, at any rate, would act as a kind of parachute in coming down. If in time of war, for instance, an ordinary steerable balloon were struck by a shell and demolished, the pilot and passengers would be lost, whereas in the case of an airship like the Malécot the men might be able to save themselves, and even escape capture, by means of this aeroplane.

In another design, the *Capazza*, the envelope is to be expanded and contracted mechanically, somewhat after the style of a concertina. The compression would so greatly increase the weight of the gas that the balloon would descend. If the balloon were expanded the gas would expand and the balloon would rise.

In the early days of the modern dirigible balloon a journey of 100 miles was remarkable. The voyage of *La Patrie*, of 160 miles, in October 1907, was hailed as a great achievement, and the Zeppelin journey round Lake Constance, a distance of 200 miles, in the same year, electrified the world. Zeppelin, however, soon followed with journeys of

270, 360, and 900 miles. The longest journey at this period was forty hours, and the highest not more than 5000 feet. But these achievements, ordinary as they now seem, were promising enough to cause great activity in the designing and building of military dirigible balloons.

It is necessary to correct a frequent error as regards the capabilities of an airship. One often hears it remarked that a dirigible balloon can "tack" after the manner of a sailing vessel. Now, it is impossible for a dirigible balloon to "tack." If its independent speed be less than the speed of an adverse wind, it has nothing to gain by attempting an oblique course and tacking. That would only result in its being driven farther away. If its speed exceeds that of the adverse wind, even slightly, it has nothing to gain by tacking. Its best course is to head straight for the goal, and make what progress it can.

Early chronicles of attempts to fly are so unreliable that it is difficult to separate truth from fiction. Some of the early records tell, with an appearance of simple fidelity, of feats that certainly never were achieved. This is probably open to a very simple explanation. If we introduce the little word "proposed" into these narratives, we shall give them the accuracy they now lack. We read of various flying apparatus with which we are told that men actually flew off high towers and other eminence, and we know that with the appliances described this could not have been the case. We also know that in all ages enthusiasts of various degrees of intelligence have proposed to perform certain feats, but have often failed, and so it is probable that many of the wonders of aviation that we read about were all of this nature.

There was no important advance in the science until Francis Wenham, in 1865 and 1867, showed that the lifting power of a plane of great superficial area could be obtained also by dividing the large plane into several parts superimposed or superposed, *i.e.* arranged in tiers. This was the germ of the modern aeroplane. This was the first glimmer of light in the darkness that beset aviation's early years. Wenham's machine had six planes. When he placed himself in a strong wind with this apparatus, he was lifted up and thrown backwards. He made further experiments, but never achieved anything approaching flight. It was not until the two Lilienthals in Germany, about the years 1885–89, discovered the possibility of driving curved aeroplanes against the wind that aviation again revived. Horatio Phillips began important investigations as to curved surfaces in 1884, and in that year Hargrave, of box-kite fame, commenced work.

Otto Lilienthal held that it was necessary to begin with "sailing" flight, and that first of all the art of balancing in the air must be learned by practical experiments. He made many flights himself of a kind we now call "gliding." From a height of 100 feet he glided a distance of 700 feet without exertion, and, moreover, he found that he could deflect his flight to the left or right by moving his legs, which were hanging freely from the seat. Lilienthal attached a light motor to his machine developing 2½ horse-power and weighing nearly 90 pounds, and he had to increase the size of his planes to sustain this weight. Unfortunately, in testing a horizontal steering arrangement, he fell from a height of 50 feet and broke his spine.

Percy S. Pilcher, a young English engineer, succeeded in 1896, with a glider of 560 square feet, weighing nearly 50 pounds, in making several good flights, attaining a speed of 30 miles an hour—enough for horizontal support. Pilcher patented his design. He built an oil-engine of four horse-power, but while in flight near Rugby a weak part of the machine broke and Pilcher fell 30 feet, and died thirty-four hours afterwards.

Chanute forged the next link in the chain. This great American experimenter directed his attention to obtaining automatic equilibrium. He departed from former practice by making the surfaces movable. In 1896 he used five large machines of four different types. The first was a Lilienthal machine, built by Chanute's assistant, A. M. Herring. But after he had made a great number of successful glides with this machine the principle of its design was decided to be unsound. Then Chanute tried a "multiple-winged" machine, consisting of four pairs of superimposed curved planes, with a single plane above all, and two wings at the rear. Three hundred flights were made with this machine, and then the "double-deck" type of rectangular planes — a distinct prototype of the Wright machine—was produced.

The machine weighed only 30 pounds. The speed was about 24 miles per hour, and the angle of descent from 7½ degrees to 11 degrees, which indicated that with a motive force of two horse-power the machine would be capable of horizontal flight. Some 700 glides were made with the apparatus without an accident.

Herring attempted to apply a motor to a "double-deck" machine, experimenting with various types of engine.

But before this period notable successes had been achieved in France and England, and in each case, curious to relate, the pioneer was regarded by his countrymen with indifference. Maxim, in 1894, made a flying-machine. He proved the efficiency of this aeroplane as a lifting apparatus, and that it did not fly was due to the fact that in those days the light petrol motor did not exist, and that Maxim had to use a steam-engine. In the previous year a Frenchman flew 500 yards even with a steam-engine, and by means of a monoplane. This inventor was Ader, and his machine, the *Avion*, was almost forgotten until the Salon of 1908. Tardy justice was then rendered to it. Ader was the victim of a conspiracy, and his success was deliberately suppressed. He was treated with disdain. He burnt all the drawings relating to his machine, and he would have burnt that had not a friend appealed to him on the ground of patriotism. It was in 1908 that the whole of the facts became public property, and France did not hesitate to render tribute to Ader's achievement. In the records of his flight Ader wrote that leaving the ground—although that was, of course, his primary object—so took him by surprise, revealing familiar objects in an entirely new aspect, that he nearly lost his senses. The machine came to grief.

Lawrence Hargrave, an Australian, in 1898 and 1899, made some remarkable experiments with soaring kites, and invented the cellular or box-kite. The principal experimenters in kites who made ascents were Le Bris in 1856, Baden-Powell in 1894, Wise in 1897, and Cody. The Farman and the first Santos-Dumont flying-machines were adaptations of the Hargrave box-kite principle.

Owing in a very large measure to the promise afforded to aviation by the introduction of the light petrol motor, progress became rapid. In 1900 Wilbur and Orville Wright, of Dayton, Ohio, achieved better results than any of their predecessors. They made gliders in which the aviator had a horizontal position, and they used twice as great a lifting surface as that hitherto employed.

E. Archdeacon, of Paris, obtained some valuable results in 1905, and in February 1905, in conjunction with the Aero Club of France, he held an exhibition of gliding apparatus and models of flying-machines.

It was on September 13, 1906, that Santos-Dumont made the first officially recorded European aeroplane flight, leaving the ground for a distance of 12 yards. On November 12 of the same year he remained in the air for 21 seconds, and travelled a distance of 230 yards.

An Englishman by birth, but a naturalised Frenchman, deserves credit for the next flight, although he made it in France. This was Henry Farman, who, on October 26, 1907, flew 820 yards in 52⅗ seconds, and quickly followed with other flights on July 6, 1908. Leon Delagrange was at this period making many flights.

These experiments, however, were being eclipsed in America by the brothers Wright; and Orville achieved a flight of over an hour's duration on September 9, 1908, and on September 12 stayed up for one hour and fourteen minutes. Then his brother Wilbur went to France and began his remarkable series of flights, often taking up passengers with him, and on December 31 he flew for two hours and nineteen minutes.

To Farman belongs the distinction of making the first cross-country journey in an aeroplane. On October 31, 1908, he flew from Chalons to Rheims, a distance of sixteen miles, in twenty minutes.

In England nothing had, so far, been done at all comparable with the achievements of the Frenchmen and Americans, and it was not until the end of 1908 that Moore-Brabazon bought a Voisin biplane, in which he made short flights in France.

Meanwhile in Canada, Douglas McCurdy was making very significant progress. The *Silver Dart* machine in which he made his trials resembled the Wright machine in that it had no tail. The supporting surfaces had only a single concave curvature, with the elevator in front and the vertical rudder in the rear. It was driven by only one propeller.

On a totally different type of machine Graham Bell was investigating in an important direction. This machine was called the *Cygnet II.*, and it consisted of some 3500 tetrahedral cells. The success achieved was spoilt by accidents, but that this type of apparatus had great possibilities was fully demonstrated.

In the United States, Glenn Curtiss constructed a biplane which in essential features resembled the Wright machine, and with it won many laurels at the Rheims Aviation Meeting. Also Cody, employed by the British War Office to make kites, achieved notable success with a biplane of the tailless type. He made some record cross-country flights, and, moreover, formally changed his nationality to British.

The Aeronautical Society of Great Britain—the oldest aeronautical society in the world—in 1908 obtained a ground for experiments at Dagenham near London, and the Aero Club obtained a ground in Sheppey.

At the close of the year the first great Aeronautical Salon was held in Paris, when upwards of a dozen full-size machines were exhibited. London followed suit three months later. Schools of aviation were opened everywhere, and scores of officers of the French army could at this time ascend in aeroplanes under the guidance of Delagrange or of Wilbur Wright.

The cross-channel flight by M. Blériot, the nearly successful attempt to perform the same feat by Mr. H. Latham, the remarkable flying achievements at Rheims, the projects by the Parliamentary Aerial Committee and the *Morning Post* for bringing dirigible balloons from France, and the ordering of a dirigible balloon of the rigid type by the British Government, combined in the summer of 1909 to create profound interest in the subject of aeronautics.

In that year the writer of these words first saw an aeroplane in the air, and it is wonderful that after so few years of work on the subject aviators had even by then arrived at the essential features of the successful flying-machine, so much so that alterations since have been only in small details.

Since there are still many people who have never seen an aeroplane, a brief general description may not be out of place.

There are two main types, biplanes and monoplanes. In the former there are two plane surfaces, one above another, connected together by struts of light metal tubes or of wood, with bracings of the same material or of wire. The planes are generally of fabric stretched on a light frame, and they are given a slight curve at the front edge, producing a concave surface as seen from below. From the centre of these main planes there usually stretches a light framing which carries the tail. Anyone who has seen a dragon-fly on the wing and can imagine it multiplied a few thousand times in size has a good idea of what an aeroplane looks like when in the sky. The main planes resemble the wings (though, of course, they do not flap), the frame carrying the tail, the body.

The tail consists generally of several planes, one or two being horizontal, and having for their object to keep the main planes tilted at the correct angle. They are adjustable, being under the control of the pilot by wires, so that they can be tilted upwards or downwards. The former raises the tail, thereby tilting the main planes downwards and steering the whole machine in a downward direction. Turning the tail planes downwards, on the other hand, tilts the main planes upwards, and so gives the machine a tendency to ascend. One certain position, of course, causes the main planes to be tilted upwards just sufficiently to keep the machine in the air at the same level. In fact, the horizontal planes in the tail are really rudders by which the machine can be steered either upwards, downwards, or in a level direction.

Combined with them are one or two planes set vertically, so as to act like the rudder of a ship, and enable the machine to be steered to either side.

In some machines, notably those of the Wright type, the elevating planes, as they are termed, are placed in front of the main planes instead of behind. Unlike the sheep in the children's rhyme, they carry their tails in front.

In general structure the monoplane is like the biplane, except that there is but one main plane instead of two.

There are a few machines of the "triplane" variety, three main planes being placed one above another.

The balancing is generally performed by warping the main planes, by giving them a twist, that is. Suppose the pilot feels himself going over to the left, he manipulates a lever which has the effect of twisting the ends of his main planes, the left-hand one in an upward direction, and the right-hand one in the opposite way. Thus he causes the left-hand end to steer itself upwards and the right hand to steer itself downwards, which soon restores his equilibrium.

He soon learns to perform this operation of balancing by instinct, just as a bicyclist does.

There are many forms of motor used in flying-machines, all of the petrol type, but there is one

which is a special favourite, known as the *Gnome*. It is **made** in France, and is the most peculiar engine in appearance that was ever seen. It has seven cylinders, arranged like the spokes of a wheel. Each cylinder works in quite an ordinary way, just like those of the ordinary motor-car engine, and they all turn one crank. At least, that is what they *don't* do, for the crank is the fixed part of the engine. It would be more correct to say that they try to turn the crank, but are unable to do so, the result being that they themselves turn round, thus forming the fly-wheel. The whole engine is, in fact, the fly-wheel. It reminds one of the riddle as to why a dog wags its tail—because the tail cannot wag the dog—the engine cannot turn the crank, and so the crank turns the engine.

Attempts have been made to use the gyroscope for balancing aeroplanes, but the simple means described just now of warping the planes seems to be very satisfactory.

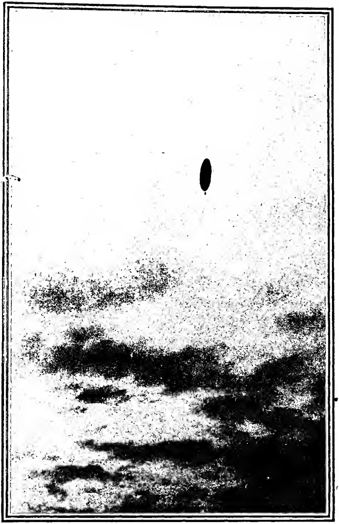
Side balance is very important, more so than in a ship for instance, for as soon as the machine tilts over to one side at all it tends to slide down the air, as it were, and fall to earth. Going round a curve an aeroplane tilts naturally, for the outer ends of the main planes have of necessity to travel farther than the inner ends, and in the same time, consequently the outer ends steer themselves upwards. This is exceedingly pretty to watch, for it gives the machine a most graceful movement, suggestive of a swallow.

Alighting on the ground, too, is very birdlike. Flying-machines have light wheels by which they can run along on the ground. There are very delicate springs in connection with these wheels to ease the jar as the machine descends, and so as it reaches the ground it gives a graceful little hop or two, just as do the sea-gulls and other birds.

To start, they run along the ground a little way on their wheels until they have secured sufficient speed to enable them to climb upwards upon the air. The Wrights originally used a kind of enormous catapult actuated by a heavy weight by which their machines were launched into the air, but that meant that they could only ascend from special places so provided. With wheels, all that is necessary is a fairly level strip of ground. The propeller pushing against the air is enough to send the machine running along, and as soon as the speed is sufficient, up it goes.

Aeroplanes for use on the water, such as those which are so ably handled by our naval officers, have light floats instead of the wheels, so that they can rise from and alight upon the water. Or they may have both, and be amphibious, so to speak.

And what use are these machines now that we have got them? Will they ever displace trains and motor-cars? At the risk of being accused of a lack of imagination, the writer says "no." Some people



M. Santos Dumont's Airship returning to Longchamps after doubling the Eiffel Tower, October 19, 1901.

[*To face p.* 300.

point to the croakers who prophesied all sorts of dangers in the early days of railways, which as we all know are now the safest places in the world. By analogy, therefore, we are told the time will probably come when the aeroplane will be safe. But the people who said silly things about railways were mostly ignorant of what railways were, or grossly prejudiced. The more one knows of the aeroplane the more does one realise how entirely dependent it is upon the most fickle of all things, the wind, "which bloweth where it listeth." If the air were always still and of practically uniform density there would be no danger. The risk of mechanical troubles, such as the stopping of the engine, is no danger, provided a safe landing-place is anywhere within reach. An aeroplane can soar for long distances with the engine stopped, and finally come to earth as gently as a bird drops on its feet. Structural weaknesses in the planes themselves, which occasionally cause an accident, will become fewer and fewer as experience grows. But those "soft places" in the air, into which a flying-machine may slide at any moment, those aerial quicksands, or the eddies and upward gusts caused by irregularities in the ground, which may at an unguarded moment tip up one end of the main planes and send the machine swiftly to destruction—no one can effectively guard against them. The most careful cyclist has an occasional fall from which he arises with but a few scratches. The analogous catastrophe in the air, caused just as simply, in itself no more dangerous, generally ends, because of the one fact of height, in the death of the unfortunate aviator.

Tennyson, in a fine passage in "Locksley Hall," turns a poetical eye towards the future. This is what he sees—

> "For I dipt into the future, far as human eye could see,
> Saw the vision of the world and all the wonder that would be,
> Saw the heavens fill with commerce, argosies of magic sail,
> Pilots of the purple twilight dropping down with costly bales,
> Heard the heavens fill with shouting, then there rained a ghostly dew,
> From the nations' airy navies, grappling in the central blue."

Expressed in more prosaic language, the flying-machine will primarily be used for military purposes. A country cannot spread a metal umbrella over itself to protect its towns from explosives dropped from the clouds.

Mail services may be revolutionised. The pleasure aeroplane may take the place of the yacht and motor-car, affording grand opportunities for the mountaineer and explorer (if the latter could find anything new to explore). Then there may also be a direct route to the North Pole over the top of those terrible icefields that have cost civilisation so many gallant lives. And possibly the ease of transit will bring the nations closer together, and produce good-fellowship and concord among them. It is pleasanter to regard the flying-machine of the future as a bringer of peace than as a novel means of spreading death and destruction, but we have grave doubts if it will ever be of much use outside warfare.

TYPE-SETTING BY MACHINERY.

To the Assyrian brickmakers who, thousands of years ago, used blocks wherewith to impress on their unbaked bricks hieroglyphics and symbolical characters, must be attributed the first hesitating step towards that most marvellous and revolutionary of human discoveries—the art of printing. Not, however, till the early part of the fifteenth century did Gutenberg and Coster conceive the brilliant but simple idea of printing from separate types, which could be set in different orders and combinations to represent different ideas. For Englishmen, 1474 deserves to rank with 1815, as in that year a very Waterloo was won on English soil against the forces of ignorance and oppression, though the effects of the victory were not at once evident. Considering the stir made at the time by the appearance of Caxton's first book at Westminster, it seems strange that an invention of such importance as the printing-press should have been frowned upon by those in power, and so discouraged that for nearly two centuries printing remained an ill-used and unprogressive art, a giant half strangled in his cradle. Yet as soon as prejudice gave it an open field, improved methods followed close on one another's heels. To-day we have in the place of Caxton's rude hand-made press great cylinder machines capable of absorbing paper by the mile, and grinding out 20,000 impressions an hour as easily as a child can unwind a reel of cotton.

Side by side with the problem how to produce the greatest possible number of copies in a given time from one machine, has arisen another:—how to set up type with a proportionate rapidity. A press without type is as useless as a chaff-cutter without hay or straw. The type once assembled, as many casts or stereotypes can be made from it as there are machines to be worked. But to arrange a large body of type in a short time brings the printer face to face with the need of employing the expensive services of a small army of compositors—unless he can attain his end by some equally efficient and less costly means. For the last century a struggle has been in progress between the machine compositor and the human compositor, mechanical ingenuity against eye and brains. In the last five years the battle has turned most decidedly in favour of the machine. To-day there are in existence two wonderful contrivances which enable a man to set up type six times as fast as he could by hand from a box of type, with an ease that reminds one of the mythical machine for the conversion of live pigs into strings of sausages by an uninterrupted series of movements.

These machines are called respectively the Linotype and Monotype. Roughly described, they are to the compositor what a typewriter is to a clerk—forming words in obedience to the depression of keys on a keyboard. But whereas the typewriter merely imprints a single character on paper, the linotype and monotype cast, deliver, and set up type from which an indefinite number of impressions can be taken. They meet the compositor more than half-way, and simplify his labour while hugely increasing his productiveness.

As far back as 1842 periodicals were mechanically composed by a machine which is now practically forgotten. Since that time hundreds of other inventions have been patented, and some scores of different machines tried, though with small success in most cases; as it was found that quality of composition was sacrificed to quantity, and that what at first appeared a short cut to the printing-press was after all the longest way round, when corrections had all been attended to. A really economical type-setter must be accurate as well as prolific. Slipshod work will not pay in the long run.

Such a machine was perfected a few years ago by Ottmar Mergenthaler of Baltimore, who devised the plan of casting a whole *line of type*. The Linotype Composing Machine, to give it its full title, produces type all ready for the presses in "slugs" or lines—hence the name, Lin' o' type. It deserves at least a short description.

The Linotype occupies about six square feet of floor space, weighs one ton, and is entirely operated by one man. Its most prominent features are a sloping magazine at the top to hold the brass matrices, or dies from which the type is cast, a keyboard controlling the machinery to drop and collect the dies, and a long lever which restores the dies to the magazine when done with.

The operator sits facing the keyboard, in which are ninety keys, variously coloured to distinguish the different kinds of letters. His hands twinkle over the keys, and the brass dies fly into place. When a key is depressed a die shoots from the magazine on to a travelling belt and is whirled off to the assembling-box. Each die is a flat, oblong brass plate, of a thickness varying with the letter, having a large V-shaped notch in the top, and the letter cut half-way down on one of the longer sides. A corresponding letter is stamped on the side nearest to the operator so that he may see what he is doing and make needful corrections.

As soon as a word is complete, he touches the "spacing" lever at the side of the keyboard. The action causes a "space" to be placed against the last die to separate it from the following word. The operations are repeated until the tinkle of a bell warns him that, though there may be room for one or two more letters, the line will not admit another whole syllable. The line must therefore be "justified," that is, the spaces between the words increased till the vacant room is filled in. In hand composition this takes a considerable time, and is irksome; but at the linotype the operator merely twists a handle and the wedge-shaped "spaces," placed thin end upwards, are driven up simultaneously, giving the lateral expansion required to make the line of the right measure.

A word about the "spaces," or space-bands. Were each a single wedge the pressure would be on the bottom only of the dies, and their tops, being able to move slightly, would admit lead between them. To obviate this a small second wedge, thin end *downwards*, is arranged to slide on the larger wedge, so that in all positions parallelism is secured. This smaller wedge is of the same shape as the dies and remains stationary in line with them, the larger one only moving.

The line of dies being now complete, it is automatically borne off and pressed into contact with the casting wheel. This wheel, revolving on its centre, has a slit in it corresponding in length and width to the size of line required. At first the slit is horizontal, and the dies fit against it so that the row of sunk letters on the faces are in the exact position to receive the molten lead, which is squirted through the slit from behind by an automatic pump, supplied from a metal-pot. The pot is kept at a proper heat of 550° Fahrenheit by the flames of a Bunsen burner.

The lead solidifies in an instant, and the "slug" of type is ready for removal, after its back has been carefully trimmed by a knife. The wheel revolves for a quarter-turn, bringing the slit into a vertical position; a punch drives out the "slug," which is slid into the galley to join its predecessors. The wheel then resumes its former horizontal position in readiness for another cast.

The assembled dies have for the time done their work and must be returned to the magazine. The mechanism used to effect this is peculiarly ingenious.

An arm carrying a ribbed bar descends. The dies are pushed up, leaving the "spaces" behind to be restored to their proper compartment, till on a level with the ribbed bar, on to which they are slid by a lateral movement, the notches of the V-shaped opening in the top side of each die engaging with the ribs on the bar. The bar then ascends till it is in line with a longer bar of like section passing over the open top of the entire magazine. A set of horizontal screw-bars, rotating at high speed, transfer the dies from the short to the long bar, along which they move till, as a die comes above its proper division of the magazine, the arrangement of the teeth allows it to drop. While all this has been going on, the operator has composed another line of moulds, which will in turn be transferred to the casting wheel, and then back to the magazine. So that the three operations of composing, casting, and sorting moulds are in progress simultaneously in different parts of the machine; with the result that as many as 20,000 letters can be formed by an expert in the space of an hour, against the 1500 letters of a skilled hand compositor.

How about corrections? Even a comma too few or too many needs the whole line cast over again. It is a convincing proof of the difference in speed between the two methods that a column of type can be corrected much faster by the machine, handicapped as it is by its solid "slugs," than by hand. No wonder then that more than 1000 linotypes are to be found in the printing offices of Great Britain.

The Monotype, like the Linotype, aims at speed in composition, but in its mechanism it differs essentially from the linotype. In the first place, the apparatus is constructed in two quite separate parts. There is a keyboard, which may be on the third floor of the printing offices, and the casting machine, which ceaselessly casts and sets type in the basement. Yet they are but one whole. The connecting link is the long strip of paper punched by the keyboard mechanism, and then transferred to the casting machine to bring about the formation of type. The keyboard is the servant of man; the casting machine is the slave of the keyboard.

Secondly, the Monotype casts type, not in blocks or a whole line, but in separate letters. It is thus a complete type-foundry. Order it to cast G's and it will turn them out by the thousand till another letter is required.

Thirdly, by means of the punched paper roll, the same type can be set up time after time without a second recourse to the keyboard, just as a tune is ground repeatedly out of a barrel organ.

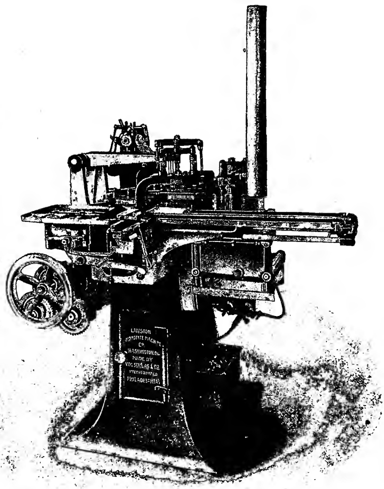
The keyboard has a formidable appearance. It contains 225 keys, providing as many characters; also thirty keys to regulate the spacing of the words. At the back of the machine a roll of paper runs over rollers and above a row of thirty little punches worked by the keys. A key being depressed, an opened valve admits air into two cylinders, each driving a punch. The punches fly up and cut two neat little holes in the paper. The roll then moves forward for the next letter. At the end of the word a special lever is used to register a space, and so on to the end of the line. The operator then consults an automatic indicator which tells him exactly how much space is left, and how much too long or too short the line would be if the spaces were of the normal size. Supposing, for instance, that there are ten spaces, and that there is one-tenth of an inch to spare. It is obvious that by extending each space one-hundredth of an inch the vacant room will be exactly filled. Similarly, if the ten normal spaces would make the line one-tenth of an inch too *long*, by *decreasing* the spaces each one-hundredth inch the line will also be "justified."

But the operator need not trouble his head about calculations of this kind. His indicator, a vertical cylinder covered with tiny squares, in each of which are printed two figures, tell him exactly what he has to do. On pressing a certain key the cylinder revolves and comes to rest with the tip of a pointer over a square. The operator at once presses down the keys bearing the numbers printed on that square, confident that the line will be of the proper length.

As soon as the roll is finished, it is detached from the keyboard and introduced to the casting machine.

Hitherto passive, it now becomes active. Having been placed in position on the rollers it is slowly unwound by the machinery. The paper passes over a hollow bar in which there are as many holes as there were punches in the keyboard, and in precisely the same position. When a hole in the paper comes over a hole in the hollow bar air rushes in, and passing through a tube actuates the type-setting machinery in a certain manner, so as to bring the desired die into contact with molten lead. The dies are, in the monotype, all carried in a magazine about three inches square, which moves backwards or forwards, to right or left, in obedience to orders from the perforated roll. The dies are arranged in exactly the same way as the keys on the keyboard. So that, supposing A to have been stamped on the roll, one of the perforations causes the magazine to slide one way, while the other shoves it another, until the combined motions bring the matrix engraved with the A underneath the small hole through which molten lead is forced. The letter is ejected and moves sideways through a narrow channel, pushing preceding letters before it, and the magazine is free for other movements.

At the end of each word a "space" or blank lead is cast, its size exactly determined by the "justifying" hole belonging to that line. Word follows word till the line is complete; then a knife-like lever rises, and the type is propelled into the "galley." Though a slave the casting machine will not tolerate injustice



By kind permission of] [*The Monotype Co.*

The Monotype Casting Machine. A punched paper roll fed through the top of the machine automatically casts and sets up type in separate letters.

[*To face p.* 312.

Should the compositor have made a mistake, so that the line is too long or too short, automatic machinery at once comes into play, and slips the driving belt from the fixed to the loose pulley, thus stopping the machine till some one can attend to it. But if the punching has been correctly done, the machine will work away unattended till, a whole column of type having been set up, it comes to a standstill.

The advantages of the Monotype are easily seen. In order to save money a man need not possess the complete apparatus. If he has the keyboard only he becomes to a certain extent his own compositor, able to set up the type, as it were by proxy, at any convenient time. He can give his undivided attention to the keyboard, stop work whenever he likes without keeping a casting-machine idle, and as soon as his roll is complete forward it to a central establishment where type is set. There a single man can superintend the completion of half-a-dozen men's labours at the keyboard. That means a great reduction of expense.

In due time he receives back his copy in the shape of set-up type, all ready to be corrected and transferred to the printing machines. The type done with, he can melt it down without fear of future regret, for he knows that the paper roll locked up in his cupboard will do its work a second time as well as it did the first. Should he need the same matter re-setting, he has only to send the roll through the post to the central establishment.

Thanks to Mr. Lanston's invention we may hope for the day when every parish will be able to do its own printing, or at least set up its own magazine. The only thing needful will be a monotype keyboard supplied by an enlightened Parish Council—as soon as the expense appears justifiable—and kept in the Post Office or Village Institute. The payment of a small fee will entitle the Squire to punch out his speech on behalf of the Conservative Candidate, the Schoolmaster to compose special information for his pupils, the Rector to reduce to print pamphlets and appeals to charity. And if those of humbler degree think they can strike eloquence from the keys, they too will of course be allowed to turn out their ideas literally by the yard.

PHOTOGRAPHY IN COLOURS.

WHILE photography was still in its infancy many people believed that, a means having been found of impressing the representation of an object on a sensitised surface, a short time only would have to elapse before the discovery of some method of registering the colours as well as the forms of nature.

Photography has during the last forty years passed through some startling developments, especially as regards speed. Experts, such as M. Marey, have proved the superiority of the camera over the human eye in its power to grasp the various phases of animal motion. Even rifle bullets have been arrested in their lightning flight by the sensitised plate. But while the camera is a valuable aid to the eye in the matter of form, the eye still has the advantage so far as colour is concerned. It is still impossible for a photographer by a simple process similar to that of making an ordinary black-and-white negative, to affect a plate in such a manner that from it prints may be made by a single operation showing objects in their natural colours. Nor, for the matter of that, does colour photography direct from nature seem much nearer attainment now than it was in the time of Daguerre.

There are, however, extant several methods of making colour photographs in an indirect or roundabout way. These various "dodges" are, apart from their beautiful results, so extremely ingenious and interesting that we propose to here examine four of the best known.

The reader must be careful to banish from his mind those *coloured* photographs so often to be seen in railway carriages and shop windows, which are purely the result of hand-work and mechanical printing, and therefore not *colour* photographs at all.

Before embarking on an explanation of these four methods it will be necessary to examine briefly the nature of those phenomena on which all are based—light and colour. The two are really identical, light is colour and colour is light.

Scientists now agree that the sensation of light arises from the wave-like movements of that mysterious fluid, the omnipresent ether. In a beam of white light several rates of wave vibrations exist side by side. Pass the beam through a prism and the various rapidities are sorted out into violet, indigo, blue, green, yellow, orange and red, which are called the pure colours, since if any of them be passed again through a prism the result is still that colour. Crimson, brown, &c., the composite colours, would, if subjected to the prism, at once split up into their component pure colours.

Photography in Colours

There are several points to be noticed about the relationship of the seven pure colours. In the first place, though they are all allies in the task of making white light, there is hostility among them, each being jealous of the others, and only waiting a chance to show it. Thus, suppose that we have on a strip of paper squares of the seven colours, and look at the strip through a piece of red glass we see only one square—the red—in its natural colour, since that square is in harmony only with red rays. (Compare the sympathy of a piano with a note struck on another instrument; if C is struck, say on a violin, the piano strings producing the corresponding note will sound, but the other strings will be silent.) The orange square suggests orange, but the green and blue and violet appear black. Red glass has arrested their ether vibrations and said "no way here." Green and violet would serve just the same trick on red or on each other. It is from this readiness to absorb or stop dissimilar rays that we have the different colours in a landscape flooded by a common white sunlight. The trees and grass absorb all but the green rays, which they reflect. The dandelions and buttercups capture and hold fast all but the yellow rays. The poppies in the corn send us back red only, and the cornflowers only blue; but the daisy is more generous and gives up all the seven. Colour therefore is not a thing that can be touched, any more than sound, but merely the capacity to affect the retina of the eye with a certain number of ether vibrations per second, and it makes no difference whether light is reflected from a substance or refracted through a substance; a red brick and a piece of red glass have similar effects on the eye.

This then is the first thing to be clearly grasped, that whenever a colour has a chance to make prisoners of other colours it will do so.

The second point is rather more intricate, viz. that this imprisonment is going on even when friendly concord appears to be the order of the day. Let us endeavour to present this clearly to the reader. Of the pure colours, violet, green and red—the extremes and the centre—are sufficient to produce white, because each contains an element of its neighbours. Violet has a certain amount of indigo, green some yellow, red some orange; in fact every colour of the spectrum contains a greater or less degree of several of the others, but not enough to destroy its own identity. Now, suppose that we have three lanterns projecting their rays on to the same portion of a white sheet, and that in front of the first is placed a violet glass, in front of the second a green glass, in front of the third a red glass. What is the result? A white light. Why? Because they meet *on equal terms*, and as no one of them is in a point of advantage no prisoners can be made and they must work in harmony. Next, turn down the violet lantern, and green and red produce a yellow, half-way between them; turn down red and turn up violet, indigo-blue results. All the way through a compromise is effected.

But supposing that the red and green glasses are put in front of the *same* lantern and the white light sent through them—where has the yellow gone to? only a brownish-black light reaches the screen. The same thing happens with red and violet or green and violet.

Prisoners have been taken, because one colour has had to *demand passage* from the other. Red says to green, "You want your rays to pass through me, but they shall not." Green retorts, "Very well; but I myself have already cut off all but green rays, and if they don't pass you, nothing shall." And the consequence of the quarrel is practical darkness.

The same phenomenon may be illustrated with blue and yellow. Lights of these two colours projected simultaneously on to a sheet yield white; but white light sent through blue and yellow glass *in succession* produces a green light. Also, blue paint mixed with yellow gives green. In neither case is there darkness or entire cutting-off of colour, as in the case of Red + Violet or Green + Red.

The reason is easy to see.

Blue light is a compromise of violet and green;

yellow of green and red. Hence the two coloured lights falling on the screen make a combination which can be expressed as an addition sum.

$$\begin{array}{rl} \text{Blue} = & \text{green} + \text{violet.} \\ \text{Yellow} = & \underline{\text{green} + \text{red.}\qquad\qquad} \\ & \text{green} + \text{violet} + \text{red} = \text{white.} \end{array}$$

But when light is passed *through* two coloured glasses in succession, or reflected from two layers of coloured paints, there are prisoners to be made.

Blue passes green and violet only.

Yellow passes green and red only.

So violet is captured by yellow, and red by blue, green being free to pass on its way.

There is, then, a great difference between the *mixing* of colours, which evokes any tendency to antagonism, and the *adding* of colours under such conditions that they meet on equal terms. The first process happens, as we have seen, when a ray of light is passed through colours *in succession;* the second, when lights stream simultaneously on to an object. A white screen, being capable of reflecting any colour that falls on to it, will with equal readiness show green, red, violet, or a combination; but a substance that is in white light red, or green, or violet will capture any other colour. So that if for the white screen we substituted a red one, violet or green falling simultaneously, would yield blackness, because red takes *both* prisoners; if it were violet, green would be captured, and so on.

From this follows another phenomenon: that whereas projection of two or more lights may yield white, white cannot result from any mixture of pigments. A person with a whole boxful of paints could not get white were he to mix them in an infinitude of different ways; but with the aid of his lanterns and as many differently coloured glasses the feat is easy enough.

Any two colours which meet on equal terms to make white are called *complementary* colours.

Thus yellow (=red+green lights) is complementary of violet.

Thus pink (=red+violet lights) is complementary of green.

Thus blue (=violet+green lights) is complementary of red.

This does not of course apply to mixture of paints, for complementary colours must act together, not in antagonism.

If the reader has mastered these preliminary considerations he will have no difficulty in following out the following processes.

(*a*) *The Joly Process,* invented by Professor Joly of Dublin. A glass plate is ruled across with fine parallel lines—350 to the inch, we believe. These lines are filled in alternately with violet, green, and red matter, every third being violet, green or red as the case may be. The colour-screen is placed in the camera in front of the sensitised plate. Upon an exposure being made, all light reflected from a red object (to select a colour) is allowed to pass through the red lines, but blocked by all the green and violet lines. So that on development that part of the negative corresponding to the position of the red object will be covered with dark lines separated by transparent belts of twice the breadth. From the negative a positive is printed, which of course shows transparent lines separated by opaque belts of twice their breadth. Now, suppose that we take the colour-screen and place it again in front of the plate in the position it occupied when the negative was taken, the red lines being opposite the transparent parts of the positive will be visible, but the green and violet being blocked by the black deposit behind them will not be noticeable. So that the object is represented by a number of red lines, which at a small distance appear to blend into a continuous whole.

The violet and green affect the plate in a corresponding manner; and composite colours will affect two sets of lines in varying degrees, the lights from the two sets blending in the eye. Thus yellow will obtain passage from both green and red, and when the screen is held up against the positive, the light streaming through the green and red lines will blend into yellow in the same manner as they would make yellow if projected by lanterns on to a screen. The same applies to all the colours.

The advantage of the Joly process is that in it only one negative has to be made.

(*b*) *The Ives Process.*—Mr. Frederic Eugene Ives, of Philadelphia, arrives at the same result as Professor Joly, but by an entirely different means. He takes three negatives of the same object, one through a violet-blue, another through a green, and a third through a red screen placed in front of the lens. The red negative is affected by red rays only; the green by green rays only, and the violet-blue by violet-blue rays only, in the proper gradations. That is to say, each negative will have opaque patches wherever the rays of a certain kind strike it; and the positive printed off will be by consequence transparent at the same places. By holding the positive made from the red-screen negative against a piece of red glass, we should see light only in those parts of the positive which were transparent. Similarly with the green and violet positives if viewed through glasses of proper colour. The most ingenious part of Mr. Ives' method is the apparatus for presenting all three positives (lighted through their coloured glasses) to the eye simultaneously. When properly adjusted, so that their various parts exactly coincide, the eye blends the three together, seeing green, red, or violet separately, or blended in correct proportions. The Kromoscope, as the viewing apparatus is termed, contains three mirrors, projecting the reflections from the positives in a single line. As the three slides are taken stereoscopically the result gives the impression of solidity as well as of colour, and is most realistic.

(*c*) *The Sanger Shepherd Process.*—This is employed mostly for lantern transparencies. As in the Ives process, three negatives and three transparent positives are made. But instead of coloured glasses being used to give effect to the positives the positives themselves are dyed, and placed one on the top of another in close contact, so that the light from the lantern passes through them in succession. We have therefore now quitted the realms of harmony for that of discord, in which prisoners are made; and Mr. Shepherd has had to so arrange matters that in every case the capture of prisoners does not interfere with the final result, but conduces to it.

In the first place, three negatives are secured through violet, green, and red screens. Positives are printed by the carbon process on thin celluloid films. The carbon film contains gelatine and bichromate of potassium. The light acts on the bichromate in such a way as to render the gelatine insoluble. The result is that, though in the positives there is at first no colour, patches of gelatine are left which will absorb dyes of various colours. The dyeing process requires a large amount of care and patience.

Now, it would be a mistake to suppose that each positive is dyed in the colour of the screen through which its negative was taken. A moment's consideration will show us why.

Let us assume that we are photographing a red object, a flower-pot for instance. The red negative represents the pot by a dark deposit. The positive printed off will consequently show clear glass at that spot, the unaffected gelatine being soluble. So that to dye the plate would be to make all red *except* the very part which we require red; and on holding it up to the light the flower-pot would appear as a white transparent patch.

How then is the problem to be solved?

Mr. Shepherd's process is based upon an ordered system of prisoner-taking. Thus, as red in this particular case is wanted it will be attained by the *other two* positives (which are placed in contact with the red positive, so that all three coincide exactly), robbing white light of all *but* its red rays.

Now if the other positives were dyed green and violet, what would happen? They would not produce red, but by robbing white light between them of red, green, and violet, would produce blackness, and we should be as far as ever from our object.

The positives are therefore dyed, not in the same colours as the screens used when the negatives were made, but in their *complementary* colours, *i.e.* as explained above, those colours which added to the colour of the screen would make white.

The red screen negative is therefore dyed (violet + green) = blue. The green negative (red + violet) = pink. The violet negative (red + green) = yellow.

To return to our flower-pot. The red-screen positive (dyed blue) is, as we saw, quite transparent where the pot should be. But behind the transparent gap are the pink and yellow positives.

White light (= violet + green + red) passes through pink (= violet + red), and has to surrender all its green rays. The violet and red pass on and encounter yellow (= green + red), and violet falls a victim to green, leaving red unmolested.

If the flower-pot had been white all three positives would have contained clear patches unaffected by the three dyes, and the white light would have been unobstructed. The gradations and mixtures of colours are obtained by two of the screens being influenced by the colour of the object. Thus, if it were crimson, both violet and red-screen negatives would be affected by the rays reflected by it, and the green screen negative not at all. Hence the pink positive would be pink, the yellow clear, and the blue clear.

White light passing through is robbed by pink of green, leaving red + violet = crimson.

(*d*) *The Lumière Process.*—In this there is a special plate on which the photograph is taken in much the ordinary way. The development is different, however, and the result is not a negative but a transparent positive.

On the glass which forms the basis of the plate there is first laid a layer of fine grains of starch. This is then covered with varnish, and upon that is the ordinary sensitive film.

The grains are previously stained, some violet, some green, and some red, being thoroughly mixed together, so that viewed by transmitted light they produce the effect almost of pure white.

Now the plate is exposed *glass side towards* the lens, and so the light first passes through the coloured grains. A ray of light strikes a violet grain; only the violet part of it passes through, reaches the film and forms a patch which on development will be dark. Thus, if violet light fell all over the plate dots would be formed over every violet grain, and the plate when held up to the light would exhibit every colour *except* violet.

Then suppose that by a second development we are able to reverse matters, so that these dark dots become clear while all else becomes dark, then the plate will appear *all violet*, for all the other grains will be covered.

In the same way red light will result in all the red grains being left uncovered, and the same with the green, so that when mixed light passes through the plate, each ray causes a patch of clear glass to be formed over the grains which it passes through.

Thus the film becomes a kind of filter full of tiny holes, each hole being over a grain which has been acted upon by a ray of its own colour. Every violet ray leaves violet grains visible, every green ray green grains, every red ray red grains. When the finished plate is examined, coloured grains are seen agreeing exactly with the coloured rays which formed the original picture.

LIGHTING.

THE production of fire by artificial means has been reasonably regarded as the greatest invention in the history of the human race. Prior to the day when a man was first able to call heat from the substances about him the condition of our ancestors must have been wretched indeed. Raw food was their portion; metals mingled with other matter mocked their efforts to separate them; the cold of winter drove them to the recesses of gloomy caverns, where night reigned perpetual.

The production of fire also, of course, entailed the creation of light, which in its developments has been of an importance second only to the improved methods of heating. So accustomed are we to our candles, our lamps, our gas-jets, our electric lights, that it is hard for us to imagine what an immense effect their sudden and complete removal would have on our existence. At times, when floods, explosions, or other accidents cause a temporary stoppage of the gas or current supply, a town may for a time be plunged into darkness; but this only for a short period, the distress of which can be alleviated by recourse to paraffin lamps, or the more homely candle.

The earliest method of illumination was the rough-and-ready one of kindling a pile of brushwood or logs. The light produced was very uncertain and feeble, but possibly sufficient for the needs of the cave-dweller. With the advance of civilisation arose an increasing necessity for a more steady illuminant, discovered in vegetable oils, burned in lamps of various designs. Lamps have been found in old Egyptian and Etruscan tombs constructed thousands of years ago. These lamps do not differ essentially from those in use to-day, being reservoirs fitted with a channel to carry a wick.

But probably from the difficulty of procuring oil, lamps fell into comparative disuse, or rather were almost unknown, in many countries of Europe as late as the fifteenth century; when the cottage and baronial hall were alike lit by the blazing torch fixed into an iron sconce or bracket on the wall.

The rushlight, consisting of a peeled rush, coated by repeated dipping into a vessel of melted fat, made a feeble effort to dispel the gloom of long winter evenings. This was succeeded by the tallow and more scientifically made wax candle, which last still maintains a certain popularity.

How our grandmothers managed to "keep their eyes" as they worked at stitching by the light of a couple of candles, whose advent was the event of the evening, is now a mystery. To-day we feel aggrieved if our lamps are not of many candle-power, and protest that our sight will be ruined by what one hundred and fifty years ago would have seemed a marvel of illumination. In the case of lighting necessity has been the mother of invention. The tendency of modern life is to turn night into day. We go to bed late and we get up late; this is perhaps foolish, but still we do it. And, what is more, we make increasing use of places, such as basements, underground tunnels, and "tubes," to which the light of heaven cannot penetrate during any of the daily twenty-four hours.

The nineteenth century saw a wonderful advance in the science of illumination. As early as 1804 the famous scientist, Sir Humphry Davy, discovered the electric arc, presently to be put to such universal use. About the same time gas was first manufactured and led about in pipes. But before electricity for lighting purposes had been rendered sufficiently cheap the discovery of the huge oil deposits in Pennsylvania flooded the world with an inexpensive illuminant. As early as the thirteenth century Marco Polo, the explorer, wrote of a natural petroleum spring at Baku, on the Caspian Sea: "There is a fountain of great abundance, inasmuch as a thousand shiploads might be taken from it at one time. This oil is not good to use with food, but it is *good to burn;* and is also used to anoint camels that have the mange. People come from vast distances to fetch it, for in all other countries there is no oil." His last words have been confuted by the American oil-fields, yielding many thousands of barrels a day—often in such quantities that the oil runs to waste for lack of a buyer.

The rivals for pre-eminence in lighting to-day are electricity, coal gas, petroleum, and acetylene gas. The two former have the advantage of being easily turned on at will, like water; the third is more generally available.

The invention of the dynamo by Gramme in 1870 marks the beginning of an epoch in the history of illumination. With its aid current of such intensity as to constantly bridge an air-gap between carbon points could be generated for a fraction of the cost entailed by other previous methods. Paul Jablochkoff devised in 1876 his "electric candle"—a couple of parallel carbon rods separated by an insulating medium that wasted away under the influence of heat at the same rate as the rods. The "candles" were used with rapidly-alternating currents, as the positive "pole" wasted twice as quickly as the negative. During the Paris Exhibition of 1878 visitors to Paris were delighted by the new method of illumination installed in some of the principal streets and theatres.

The arc-lamp of to-day, such as we see in our streets, factories, and railway stations, is a modification of M. Jablochkoff's principle. Carbon rods are used, but they are pointed towards each other, the distance between their extremities being kept constant by ingenious mechanical contrivances. Arc-lamps of all types labour under the disadvantage of being, by necessity, very powerful; and were they only available the employment of electric lighting would be greatly restricted. As it is, we have, thanks to the genius of Mr. Edison, a means of utilising current in but small quantities to yield a gentler light. The glow-lamp, as it is called, is so familiar to us that we ought to know something of its antecedents.

In the arc-lamp the electric circuit is *broken* at the point where light is required. In glow or incandescent lamps the current is only *hindered* by the interposition of a bad conductor of electricity, which must also be incombustible. Just as a current of water flows in less volume as the bore of a pipe is reduced, and requires that greater pressure shall be exerted to force a constant amount through the pipe, so is an electric current *choked* by its conductor being reduced in size or altered in nature. Edison in 1878 employed as the current-choker a very fine platinum wire, which, having a melting temperature of 3450 degrees Fahrenheit, allowed a very white heat to be generated in it. The wire was enclosed in a glass bulb almost entirely exhausted of air by a mercury-pump before being sealed. But it was found that even platinum could not always withstand the heating effect of a strong current; and accordingly Edison looked about for some less combustible material. Mr. J. W. Swan of Newcastle-on-Tyne had already experimented with carbon filaments made from cotton threads steeped in sulphuric acid. Edison and Swan joined hands to produce the present well-known lamp, "The Ediswan," the filament of which is a bamboo fibre, carbonised during the exhaustion of air in the bulb to one-millionth of an atmosphere pressure by passing the electric current through it. These bamboo filaments are very elastic and capable of standing almost any heat.

Glow-lamps are made in all sizes—from tiny globes small enough to top a tie-pin to powerful lamps of 1000 candle-power. Their independence of atmospheric air renders them most convenient in places where other forms of illumination would be dangerous or impossible; *e.g.* in coal mines, and under water during diving operations. By their aid great improvements have been effected in the lighting of theatres, which require a quick switching on and off of light. They have also been used in connection with minute cameras to explore the recesses of the human body. In libraries they illuminate without injuring the books. In living rooms they do not foul the air or blacken the ceiling like oil or gas burners. The advantages of the "Edison lamp" are, in short, multitudinous.

Cheapness of current to work them is, of course, a very important condition of their economy. In some small country villages the cottages are lit by electricity even in England, but these are generally within easy reach of water power. Mountainous districts, such as Norway and Switzerland, with their rushing streams and high waterfalls, are peculiarly suited for electric lighting: the cost of which is mainly represented by the expense of the generating apparatus and the motive power.

But just as the electric glow-lamp seemed likely to make inroads into the profits of the gasworks, a great German scientist, von Welsbach by name, brought out the "mantle" which bears his name. This is made of cotton fabric impregnated with certain rare elements, with curious names such as "thorium" and "cerium," and stiffened with a kind of varnish. When first lit the varnish and the cotton are burnt away, and the delicate skeleton of thorium, &c., left. The gas, which is burnt below it in a burner of the well-known bunsen type, heats the mantle and causes it to glow very brightly. Thus the gas really heats only, it does not itself give light, while in the ordinary gas-flame the gas itself, or rather the tiny particles of carbon in it, give the light.

This mantle was latter improved by being turned upside down and hung at the bottom of the burner, which was inverted too. And so came about the familiar "inverted Welsbach" burner.

The Welsbach burner with its mantle gives us a better light, with more light rays and less heat rays than the ordinary gas-burner does. It gives it, too, at a much smaller expenditure of gas. The writer knows a large building which used to have the ordinary burners. These were controlled by a series of taps, each of which had a by-pass beside it, by which is meant a little branch pipe controlled by a small tap, the idea being that when the by-pass tap was turned on just enough gas passed to keep the burners from going quite out. On the by-pass they used to glimmer only. But now Welsbach burners are used, and the by-pass taps supply all the gas required to keep them on full. The large taps can be closed entirely without making any difference to the light in the building. In other words, the amount of gas which barely kept the old burners alight supplies the new ones fully.

So after the introduction of the Welsbach burner the electric lighting industry began to have a bad time, for by its aid gas-light became ever so much cheaper, and because of its bluer light much better to work by. But the fight was not over, for presently the metal filament electric lamp came along and did for electric lighting very much what the mantle did for gas.

We have already explained the older carbon filament lamp. The metal filament lamp is just the same, except for the peculiarity which gives it its name. Instead of the fine thread of carbon inside the bulb, it has one made of one of the rare metals. Osmium, tungsten, tantallum—these hitherto seldom-heard-of metals are well known now because of the lamps to which they have given their names. At first there was a difficulty in making them into the fine threads necessary for this purpose. Osmium lamps, for example, used to have filaments made in this way. The metal in a finely divided form was mixed with a cement, the mixture being then moulded into threads. After that it was heated by electricity which burnt the cement out of it and left the metal alone, the small particles being, as it were, welded together. Means have now been found whereby the metals can be drawn into thin wires in the way in which wires are usually made.

These metal filament lamps give better light, more like that from the Welsbach mantle, and use less current than the older ones did.

The high-pressure incandescent gas installations of Mr. William Sugg supply gas to burners at five or six times the ordinary pressure of the mains. The effect is to pulverise the gas as it issues from the nozzle of the burners, and, by rendering it more inflammable, to increase its heating power until the surrounding mantle glows with a very brilliant and white light of great penetration. Gas is forced through the pipes connected with the lamps by hydraulic rams working gas-pumps, which alternately suck in and expel the gas under a pressure of twelve inches (*i.e.* a pressure sufficient to maintain a column of water twelve inches high). The gas under this pressure passes into a cylinder of a capacity considerably greater than the capacity of the pumps. This cylinder neutralises the shock of the rams, when the stroke changes from up- to downstroke, and *vice versâ*. On the top of the cylinder is fixed a governor consisting of a strong leathern gas-holder, which has a stroke of about three inches, and actuates a lever which opens and closes the valve through which the supply of water to the rams flows, and reduces the flow of the water when it exceeds ten or twelve inches pressure, according to circumstances. The gas-holder of the governor is lifted by the pressure of the gas in the cylinder, which passes through a small opening from the cylinder to the governor so as not to cause any sudden rise or fall of the gas-holder. By this means a nearly constant pressure is maintained; and from the outlet of the cylinder the gas passes to another governor sufficient to supply the number of lights the apparatus is designed for, and to maintain the pressure without variation whether all or a few lamps are in action. For very large installations steam is used.

Each burner develops 300 candle-power. A double-cylinder steam-engine working a double pump supplies 300 of these burners, giving a total lighting-power of 90,000 candles. As compared with the cost of low-pressure incandescent lighting the high-pressure system is very economical, being but half as expensive for the same amount of light.

It is largely used in factories and railway stations. It has been used on the Tower Bridge, Blackfriars Bridge, Euston Station, and in the terminus of the Great Central Railway, St. John's Wood.

Perhaps the most formidable rival to the electric arc-lamp for the lighting of large spaces and buildings is the Kitson Oil Lamp, now so largely used in America and this country.

The lamp is usually placed on the top of an iron post similar to an ordinary gas-light standard. At the bottom of the post is a chamber containing a steel reservoir capable of holding from five to forty gallons of petroleum. Above the oil is an air-space into which air has been forced at a pressure of fifty lbs. to the square inch, to act as an elastic cushion to press the oil into the burners. The oil passes upwards through an extremely fine tube scarcely thicker than electric incandescent wires to a pair of cross tubes above the burners. The top one of these acts as a filter to arrest any foreign matter that finds its way into the oil; the lower one, in diameter about the size of a lead-pencil and eight inches long, is immediately above the mantles, the heat from which vaporises the small quantity of oil in the tube. The oil-gas then passes through a tiny hole no larger than a needle-point into an open mixing-tube where sufficient air is drawn in for supporting combustion. The mixture then travels down to the mantle, inside which it burns.

An ingenious device has lately been added to the system for facilitating the lighting of the lamp. At the base of the lamp-post a small hermetically-closed can containing petroleum ether is placed, and connected by very fine copper-tubing with a burner under the vaporising tube. When the lamp is to be lit a small rubber bulb is squeezed, forcing a quantity of the ether vapour into the burner, where it is ignited by a platinum wire rendered incandescent by a current passing from a small accumulator also placed in the lamp-post. The burner rapidly heats the vaporising tube, and in a few moments oil-gas is passing into the mantles, where it is ignited by the burner.

So economical is the system that a light of 1000 candle-power is produced by the combustion of about half a pint of petroleum per hour!

There are several systems of lighting by means of petrol vapour. A simple little engine of some sort is made to pump air through a vessel containing petrol, and passing over it it takes up sufficient of the vapour which that liquid gives off to burn in specially constructed burners of the Welsbach type.

This is often used for country houses and other isolated places where coal-gas is not procurable. The engine is sometimes a hot-air motor, a very convenient and safe way of generating small power. It can be made to work with little supervision, being regulated by the gas-holder. This is just like a very small model of the holders which we see at the gasworks, and as it rises, showing that it is nearly full, it slows down the engine, while when it falls the engine starts again. Thus the plant is very easily looked after, and the chauffeur, who is now an institution at all country houses, is well able to take care of it.

The oil system that we have noticed at some length has been adapted for lighthouse use, as it gives a light peculiarly fog-piercing. It is said to approximate most closely to ordinary sunlight, and on that account has been found very useful for the taking of photographs at night-time. The portability of the apparatus makes it popular with contractors; and the fact that its installation requires no tearing up of the streets is a great recommendation with the long-suffering public of some of our large towns.

Another very powerful light is produced by burning the gas given off by carbide of calcium when immersed in water. *Acetylene* gas, as it is called, is now widely used in cycle and motor lamps, which emit a shaft of light sometimes painfully dazzling to those who have to face it. In Germany the gas is largely employed in village streets; and in this country it is gaining ground as an illuminant of country houses, being easy to manufacture—in small gasometers of a few cubic yards capacity—and economical to burn.

Well supplied as we are with lights, we find, nevertheless, that savants are constantly in pursuit of an *ideal* illuminant.

From the sun are borne to us through the ether light waves, heat waves, magnetic waves, and other waves of which we have as yet but a dim perception. The waves are commingled, and we are unable to separate them absolutely. And as soon as we try to copy the sun's effects as a source of heat or light we find the same difficulty. The fire that cooks our food gives off a quantity of useless light-waves;

the oil-lamp that brightens one's rooms gives off a quantity of useless, often obnoxious, heat.

The ideal illuminant and the ideal heating agent must be one in which the required waves are in a great majority. Unfortunately, even with our most perfected methods, the production of light is accompanied by the exertion of a disproportionate amount of wasted energy. In the ordinary incandescent lamp, to take an instance, only 5 or 6 per cent. of the energy put into it as electricity results in light. The rest is dispelled in overcoming the resistance of the filament and agitating the few air-molecules in the bulb. To this we must add the fact that the current itself represents but a fraction of the power exerted to produce it. The following words of Sir Oliver Lodge are to the point on this subject:—

"Look at the furnaces and boilers of a steam-engine driving a group of dynamos, and estimate the energy expended; and then look at the incandescent filaments of the lamps excited by them, and estimate how much of their radiated energy is of real service to the eye. It will be as the energy of a pitch-pipe to an entire orchestra.

"It is not too much to say that a boy turning a handle could, if his energy were properly directed, produce quite as much real light as is produced by all this mass of mechanism and consumption of material."[1]

---

[1] Sir Oliver Lodge, in a lecture to the Ashmolean Society, 3rd June 1889.

The most perfect light in nature is probably that of the glow-worm and firefly—a phosphorescent or "cold" light, illuminating without combustion owing to the absence of all waves but those of the requisite frequency. The task before mankind is to imitate the glow-worm in the production of isolated light-waves.

The nearest approach to its achievement has occurred in the laboratories of Mr. Nikola Tesla, the famous electrician. By means of a special oscillator, invented by himself, he has succeeded in throwing the ether particles into such an intense state of vibration that they become luminous. In other words, he has created vibrations of the enormous rapidity of light, and this without the creation of heat waves to any appreciable extent.

An incandescent lamp, mounted on a powerful coil, is lit *without* contact by ether waves transmitted from a cable running round the laboratory, or bulbs and tubes containing highly rarefied gases are placed between two large plate-terminals arranged on the end walls. As soon as the bulbs are held in the path of the currents passing through the ether from plate to plate they become incandescent, shining with a light which, though weak, is sufficiently strong to take photographs by with a long exposure. Tesla has also invented what he calls a "sanitary" light, as he claims for it the germ-killing properties of sunshine. The lamps are glass tubes several feet long, bent into spirals or other convolutions, and filled before sealing with a certain gas. The ends of the glass tube are coated with metal and provided with hooks to connect the lamp with an electric current. The gas becomes *luminous* under the influence of current, but not strictly incandescent, as there is very little heat engendered. This means economy in use. The lamps are said to be cheaply manufactured, but as yet they are not "on the market." We shall hear more of them in the near future, which will probably witness no more interesting development than that of lighting.

Before closing this chapter a few words may be said about new heating methods. Gas stoves are becoming increasingly popular by reason of the ease with which they can be put in action and made to maintain an even temperature. But the most up-to-date heating apparatus is undoubtedly electrical. Whenever current passes along a conductor it generates heat, and if the conductor be a fine wire and the current sufficiently strong, the heat is very great. We see that in an electric glow-lamp. Much of the heat is kept in there, however, by being enclosed in a vacuum, but if a suitable metal which will not melt or burn be employed the vacuum is not necessary and then the heat flows out from it freely, and can be radiated into the air or used for cooking.

In all parts of the house the electric current may be made to do work besides that of lighting. It warms the passages by means of special radiators—replacing the clumsy coal and "stuffy" gas stove; in the kitchen it boils, stews, and fries, heats the flat-irons and ovens; in the breakfast room boils the kettle, keeps the dishes, teapots, and coffee-pots warm; in the bathroom heats the water; in the smoking-room replaces matches; in the bedroom electrifies foot-warmers, and — last wonder of all — even makes possible an artificially warm bed-quilt to heat the chilled limbs of invalids!

The great advantage of electric heating is the freedom from all smell and smoke that accompanies it. But until current can be provided at cheaper rates than prevail at present, its employment will be chiefly restricted to the houses of the wealthy or to large establishments, such as hotels, where it can be used on a sufficient scale to be comparatively economical.

THE END

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